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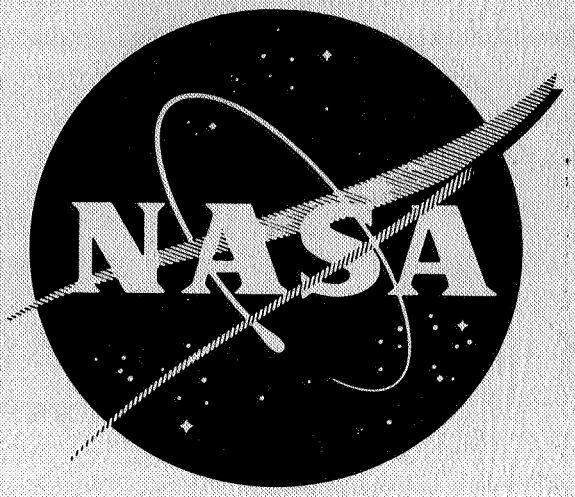

ADVANCED REFRACTORY ALLOY CORROSION LOOP PROGRAM

Quarterly Progress Report No. 8
For Quarter Ending April 15, 1967

By

R. W. HARRISON
and
E. E. HOFFMAN

prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
CONTRACT NAS 3-6474

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC
CINCINNATI, OHIO 45215

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National Aeronautics & Space Administration
21000 Brookpark Road
Cleveland, Ohio 44135
Attn: Contracting Officer
Space Power Systems Procurement Section
MS 500-309

ADVANCED REFRACTORY ALLOY CORROSION LOOP PROGRAM

QUARTERLY PROGRESS REPORT 8

Covering the Period

January 15, 1967 to April 15, 1967

Edited by

R. W. Harrison

Project Metallurgist

Approved by

E. E. Hoffman

Manager, Corrosion Technology

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Lewis Research Center

Under Contract NAS 3-6474

Technical Management
NASA - Lewis Research Center
Space Power Systems Division
R. L. Davies

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO 45215

FOREWORD

The work described herein is sponsored by the National Aeronautics and Space Administration under Contract NAS 3-6474. For this program, Mr. R. L. Davies is the NASA Project Manager.

The program is being administered for the General Electric Company by Dr. J. W. Semmel, Jr., and E. E. Hoffman is acting as the Program Manager. J. Holowach, the Project Engineer, is responsible for the loop design, facilities procurement and test operations. R. W. Harrison, the Project Metallurgist, is responsible for the materials procurement, utilization and evaluation aspects of the program. Personnel making major contributions to the program during the current reporting period include:

Alkali Metal Purification and Handling - Dr. R. B. Hand, L. E. Dotson and H. Bradley.

Welding and Joining - W R. Young and S. R. Thompson.

Refractory Alloy Procurement - R. G. Frank and L. B. Engel, Jr.

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ADVANCED REFRACTORY ALLOY CORROSION LOOP PROGRAM

I. INTRODUCTION

This report covers the period from January 15, 1967 to April 15, 1967. The primary task of this program is to fabricate, operate for 10,000 hours and evaluate a T-111 Rankine System Corrosion Test Loop. Materials for evaluation include the containment alloy, T-111 (Ta-8W-2Hf) and the turbine candidate materials Mo-TZC and Cb-132M which are located in the turbine simulator of the two-phase potassium circuit of the system. The loop design will be similar to the Cb-1Zr Rankine System Corrosion Loop; a two-phase, forced convection, potassium corrosion test loop which has been developed under Contract NAS 3-2547. Lithium will be heated by direct resistance in a primary loop. Heat rejection for condensation in the secondary potassium loop will be accomplished by radiation in a high vacuum environment to the water cooled chamber. The compatibility of the selected materials will be evaluated at conditions representative of space electric power system operating conditions, namely:

a. Boiling temperature, 2050°F
b. Superheat temperature, 2150°F
c. Condensing temperature, 1400°F
d. Subcooling temperature, 1000°F
e. Mass flow rate, 40 lb/hr
f. Boiler exit vapor velocity, 50 ft/sec
g. Average heat flux in plug (0-18 inches), 240,000 BTU/hr ft^2
h. Average heat flux in boiler (0-250 inches), 23,000 BTU/hr ft^2

In addition to the primary program task cited above the program also includes capsule testing to evaluate advanced tantalum alloys of the ASTAR 811 type (Ta-8W-1Hf-1Re) in both potassium and lithium.

Also included in the program is the fabrication, 5000-hour operation and evaluation of a 2600°F, high flow velocity, pumped lithium loop designed to evaluate the compatibility of the ASTAR 811 type alloys, T-111, T-222, and the tungsten alloy, W-25Re-30Mo.

II. SUMMARY

All the refractory alloy materials for construction of Corrosion Loop I (T-111) have been received and quality assurance inspected.

A trial lithium distillation run is in progress to determine the operational characteristics and the extent of lithium purification achieved by distillation.

Fabrication of loop components is in progress with most major components nearing completion.

The ASTAR 811 and ASTAR 811CN tantalum alloy specimens have been contaminated with oxygen to the desired levels in preparation for the lithium and potassium capsule tests.

III. PROGRAM STATUS

A. MATERIALS PROCUREMENT

All the refractory alloy materials for construction of Corrosion Loop I (T-111) have been received and quality assurance inspected.

1. T-111 Alloy

The quality assurance inspection of the 0.375-inch OD and 1.0-inch OD T-111 alloy tubing has been completed. Eighty-three percent of the 0.375-inch OD T-111 alloy tubing received met the requirements of SPPS Specification 01-0035-00-B, "Seamless Tubing and Pipe: T-111 (Ta-8W-2Hf) Alloy." Table I illustrates the distribution of usable lengths of the 0.375-inch OD tubing after removal of all non-acceptable defects. All of the 1.0-inch OD T-111 alloy tubing passed the quality assurance inspection performed by General Electric.

During the sampling of the T-111 alloy tubing for the quality assurance tests, severe radial cracking was observed on surfaces cut with an abrasive cut-off wheel as illustrated in Figure 1. The cracks were greatly accented by flattening the cut tube. After flattening, it was apparent that the cracks were concentrated on the side of the tube that made the initial contact with the abrasive cut-off wheel. The belief that the cracking was caused by the action of the abrasive cut-off wheel was substantiated by the fact that removal of the cut surface of the tube by grinding resulted in no cracking in the tube upon flattening, Figure 2. The abrasive wheel used for these cuts was an Allison* aluminum oxide wheel, designation VA1202MRA. Subsequently an Allison silicon carbide abrasive wheel, C120KRA, was used to cut the T-111 alloy tubing with greatly improved results, Figure 3. Although cracking of the T-111 alloy tubing due to cutting with an abrasive wheel was essentially eliminated, with the use of a silicon carbide wheel (C120KRA), a

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*Allison-Campbell Division, American Chain and Cable Company, Bridgeport, Connecticut.

TABLE I. DISTRIBUTION OF USABLE LENGTHS[1] OF 0.375-INCH OD T-111 ALLOY TUBING

Range of Length ℓ in Feet	Number of Tubes Within Range
$0 < \ell \leq 1$	14
$1 < \ell \leq 2$	17
$2 < \ell \leq 3$	13
$3 < \ell \leq 4$	6
$4 < \ell \leq 5$	4
$5 < \ell \leq 6$	4
$6 < \ell \leq 7$	2
$7 < \ell \leq 8$	4
$8 < \ell$	1

C1238-1

(1) Passed SPPS specification 01-0035-00-B "Seamless Tubing and Pipe: T-111 (Ta-8W-2Hf) Alloy."

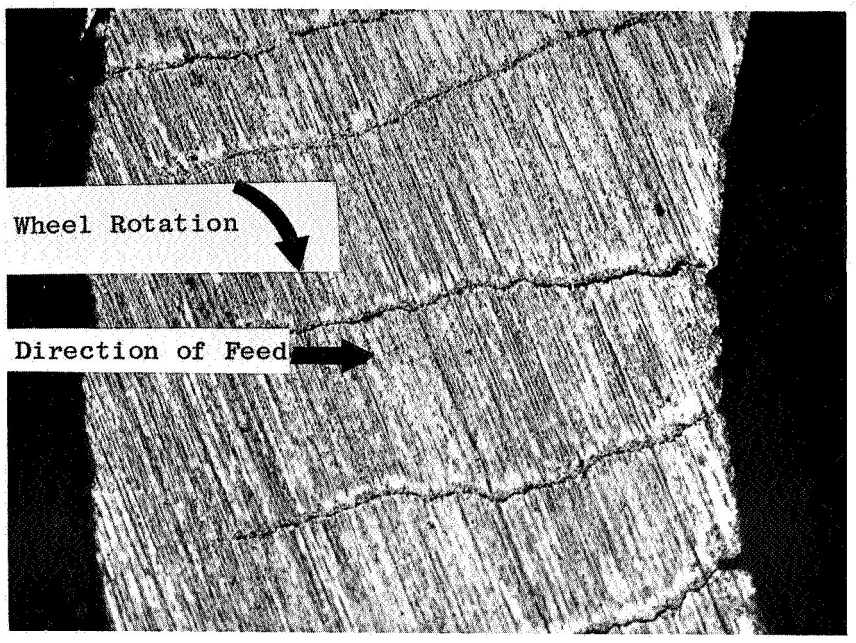
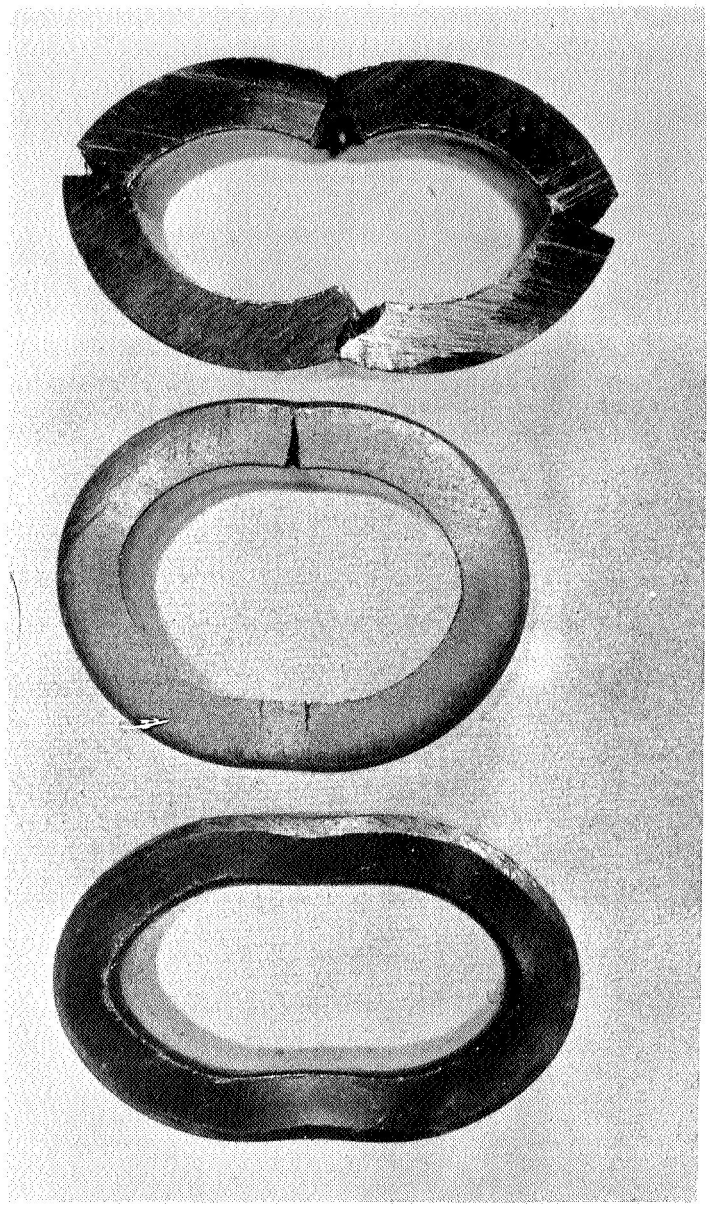


Figure 1. Radial Cracks in 0.375-Inch OD x 0.065-Inch Wall T-111 Alloy Tubing (MCN02A0066-3) After Cutting With an Allison VA1202MRA Alumina Abrasive Wheel.

(Orig. D160112) Magnification: 50X

C1238-2



a) Bent as Cut.

b) 0.040" Ground Off Cut Surfaces Prior to Bending

c) 0.10" Ground Off Cut Surfaces Prior to Bending

Figure 2. Samples of Flattened 0.375-Inch OD x 0.065-Inch Wall T-111 Alloy Tubing After Cutting With an Allison VA1202MRA Alumina Abrasive Wheel Showing the Beneficial Effect of Removing the Surface Layer After Cutting. Orig. C66122323

C1238-3

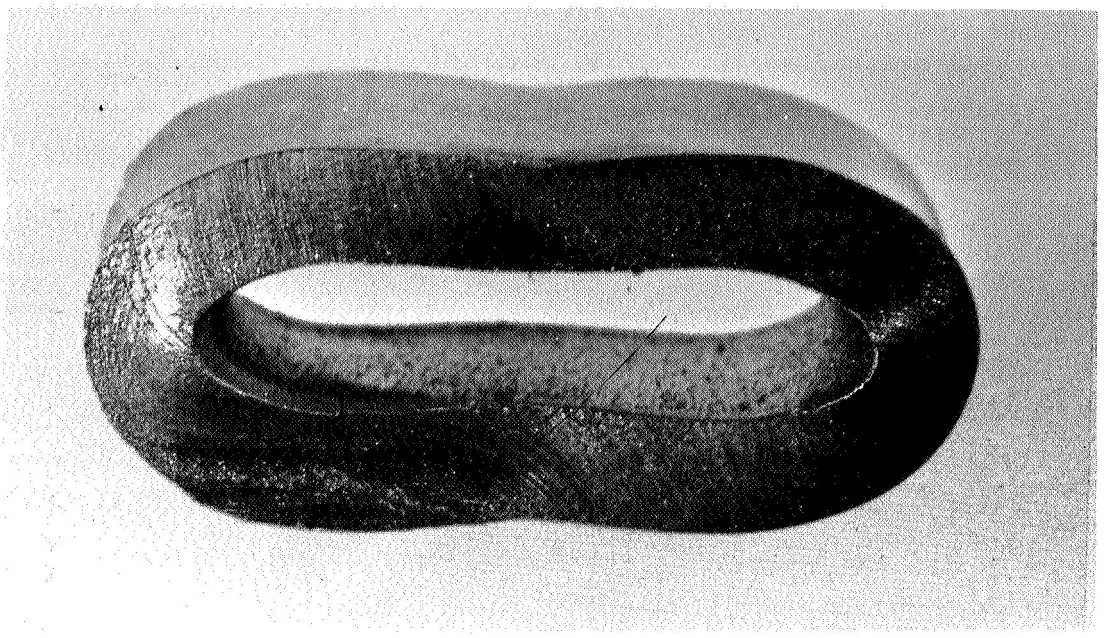


Figure 3. Flattened 0.375-Inch OD x 0.065-Inch Wall T-111 Alloy Tube After Cutting With an Allison C120KRA Silicon Carbide Abrasive Wheel. The Cut Surface was not Ground Back Prior to Flattening.

(Orig. C66121614)

C1238-4

few very small cracks still were observed in portions of the cut tubes. As a result, it is necessary to exercise extreme care in using an abrasive wheel for cutting T-111 alloy mill products when cracks cannot be tolerated. Under these conditions, the cut surfaces should be ground back, etched, and penetrant inspected, in order to be sure that all cracks have been removed.

All of the products made from the fourth and fifth T-111 alloy ingots (Number 111-D-1102 and Number 111-D-1765, respectively) have been received, and General Electric SPPS quality assurance inspection and testing of this material has been completed. A portion of this material has been released for manufacture.

Final annealing (3000°F for one hour) of the products made from the sixth T-111 alloy ingot (Number 111-D-1829) was completed on February 3, 1967 at Wolverine Tube. The final machining of these products was completed at Iverson Industries and all the items from this ingot have been received. General Electric SPPS quality assurance inspection and testing of these products is now in progress. The products obtained from this ingot are for back-up purposes and are not critical to initiating the loop fabrication phase of this program.

2. Quality Assurance for Refractory Metal Mill Products

The quality assurance program was established to provide adequate identification and documentation of the quality of the refractory metals and alloys used in the construction of Corrosion Loop I (T-111). The majority of the quality assurance measures were performed and certified to be within specification by the materials producers; check tests performed by the General Electric Company generally were limited to chemical analyses of the interstitial elements, metallographic examination, hardness measurements, and visual inspection of the incoming products.

Upon receipt of material from the material producers, a Material Control Number (MCN) was assigned to each homogeneous lot of material. A homogeneous lot includes all material of the same size, shape, condition, and finish from one heat of material and which has received the same processing, has been

TABLE II. RESULTS OF QUALITY ASSURANCE TEST PROGRAM

Alloy	MCN Number	Mill Product Form	Mill Product Size	Vendor	Heat Number	Specifications Number	Specifications Major Exceptions	Meets All Specification Requirements	Remarks
T-111	02B-011	Foil	0.005" x 3.5" x 52"	Fansteel	111-D-1632	01-0043-00-A	None	Yes	
	02A-042	Foil	0.005" x 3.5" x 52"	Fansteel	111-D-1670	01-0043-00-A	None	Yes	
	02A-064	Foil	0.005" x 3.5" x 52"	Wah Chang	65076	01-0043-00-A	None	Yes	
	02B-012	Foil	0.009" x 3.5" x 12"	Fansteel	111-D-1632	01-0043-00-A	None	No	High oxygen (238 ppm).
	02A-043	Foil	0.009" x 3.5" x 12"	Fansteel	111-D-1670	01-0043-00-A	None	Yes	
	02A-063-(1-2)	Foil	0.009" x 3.5" x 12"	Wah Chang	65076	01-0043-00-A	None	No	Surface imperfections.
	02A-065-(1-3)	Sheet	0.035" x 1" x 14"	Wah Chang	65076	01-0040-00-B	None	Yes	
	02B-010-(1-2)	Sheet	0.040" x 12" x 50"	Fansteel	111-D-1632	01-0040-00-B	None	No	Stress-rupture life below minimum.(1)
	02A-057	Sheet	0.125" x 6" x 10"	Wah Chang	65076	01-0040-00-B	None	No	High carbon (80 ppm).
	02B-009	Plate	0.500" x 6.125" x 11"	Fansteel	111-D-1632	01-0040-00-B	None	No	Stress-rupture life below minimum.(1)
	02A-056	Plate	0.500" x 6.125" x 11"	Wah Chang	65076	01-0040-00-B	None	Yes	
	02A-066-(1-3)	Tube	0.375" OD x 0.065"wall x 144"	Fansteel	111-D-1670	01-0035-00-B	None	Yes	Failed visual, ultrasonic & penetrant inspection; all defects removed.
	02A-067-(1-18)	Tube	0.375" OD x 0.065" wall x 72"	Fansteel	111-D-1670	01-0035-00-B	None	Yes	
	02A-068-(1-2)	Tube	1.0" OD x 0.100" wall x 140"	Fansteel	111-D-1670	01-0035-00-B	None	Yes	
	02A-074	Tube	1.0" OD x 0.100" wall x 112"	Fansteel	111-D-1670	01-0035-00-B	None	Yes	
	02A-075-(1-2)	Tube	1.0" OD x 0.100" wall x 9'	Fansteel	111-D-1670	01-0035-00-B	None	Yes	
	02A-079-(1-2)	Tube	2.250" OD x 0.375" wall x 15"	Fansteel	111-D-1765	01-0035-00-B	None	Yes	
	02A-085	Tube	2.50" OD x 1.610" ID x 13"	Fansteel	111-D-1829	01-0035-01-D	None	Yes	
	02A-080	Tube	2.50" OD x 1.610" ID x 13"	Fansteel	111-D-1765	01-0035-00-B	None	Yes	
	02A-046-(1-2)	Tube	3.0" OD x 0.375" wall x 13"	Fansteel	111-D-1102	01-0035-00-B	None	Yes	
	02A-048	Tube	3.25" OD x 0.250" wall x 14"	Fansteel	111-D-1102	01-0035-00-B	None	Yes	
	02A-045	Tube	3.25" OD x 0.500" wall x 14"	Fansteel	111-D-1102	01-0035-00-B	None	Yes	
	02A-086	Tube	3.25" OD x 0.25" wall x 14"	Fansteel	111-D-1829	01-0035-01-D	None	Yes	
	02A-087	Tube	3.25" OD x 0.50" wall x 14"	Fansteel	111-D-1829	01-0035-01-D	None	Yes	

TABLE II. (Cont.)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Vendor	Heat Number	Specifications Number	Specifications Major Exceptions	Meets All Specification Requirements	Remarks
T-111	02B-001	Wire	0.062" diameter x 6 lbs	Fansteel	111-D-1633	01-0048-00-A	None	Yes	
	02A-039-(1-2)	Wire	0.062" diameter x 6.47 lbs	Wah Chang	70616	01-0048-00-A	None	Yes	
	02B-002	Wire	0.094" diameter x 8 lbs	Fansteel	111-D-1633	01-0048-00-A	None	Yes	
	02B-003	Wire	0.125" diameter x 168'	Fansteel	111-D-1633	01-0048-00-A	None	Yes	
	02A-059	Wire	0.125" diameter x 40'	Wah Chang	70616	01-0048-00-A	None	Yes	
	02A-060	Wire	0.125" diameter x 7.9 lbs	Wah Chang	65076	01-0048-00-A	None	Yes	
	02A-073	Wire	0.125" diameter x 4.4 lbs	Wah Chang	65077	01-0048-00-A	None	Yes	
	02B-004	Rod	0.250" diameter x 24"	Fansteel	111-D-1633	01-0015-00-B	None	No	Stress-rupture life below min.(2)
	02A-054	Rod	0.250" diameter x 24"	Wah Chang	65076	01-0015-00-B	None	Yes	Failed penetrant inspection; defects removed.
	02B-005	Rod	0.500" diameter x 48"	Fansteel	111-D-1633	01-0015-00-B	None	No	Stress-rupture life below min.(2)
	02A-052	Rod	0.500" diameter x 48"	Wah Chang	65076	01-0015-00-B	None	Yes	
	02B-006	Rod	0.625" diameter x 14"	Fansteel	111-D-1633	01-0015-00-B	None	No	Stress-rupture life below min.(2)
	02A-053	Rod	0.625" diameter x 14"	Wah Chang	65076	01-0015-00-B	None	Yes	
	02B-007-(1-2)	Rod	1.0" diameter x 42"	Fansteel	111-D-1633	01-0015-00-B	None	No	Stress-rupture life below min.(2)
	02A-062	Rod	1.0" diameter x 42"	Wah Chang	65076	01-0015-00-B	None	Yes	
	02B-008	Rod	1.125 "diameter x 8"	Fansteel	111-D-1633	01-0015-00-B	None	No	Stress-rupture life below min.(2)
	02A-061	Rod	1.125" diameter x 8"	Wah Chang	65076	01-0015-00-B	None	Yes	
	02B-014	Rod	1.50" diameter x 6"	Fansteel	111-D-1633	01-0015-00-B	None	No	Failed grain size requirement.
	02A-058	Rod	1.50" diameter x 6"	Wah Chang	65076	01-0015-00-B	None	Yes	
	02A-044-(1-3)	Rod	2.0" diameter x 21"	Fansteel	111-D-1102	01-0015-00-B	None	Yes	
	02A-082	Rod	2.0" diameter x 24"	Fansteel	111-D-1829	01-0015-00-B	None	Yes	
	02A-038	Rod	2.5" diameter x 21 1/16"	Fansteel	111-D-1670	01-0015-00-B	None	Yes	
	02A-077	Rod	2.5" diameter x 5.188"	Fansteel	111-D-1765	01-0015-00-B	None	Yes	
	02A-083	Rod	2.5" diameter x 5"	Fansteel	111-D-1829	01-0015-00-B	None	Yes	
	02A-076	Rod	3.125" diameter x 16"	Fansteel	111-D-1765	01-0015-00-B	None	Yes	Failed ultrasonic inspection; defect removed.

TABLE II. (Cont.)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Vendor	Heat Number	Specifications Number	Specifications Major Exceptions	Meets All Specification Requirements	Remarks
T-111	02B-013-(1-3)	Bar	1" x 1" x 12.5"	Fansteel	111-D-1633	01-0015-00-B	None	No	Failed grain size requirement.
	02A-051	Bar	1" x 1" x 12.5"	Wah Chang	65076	01-0015-00-B	None	Yes	
	02A-047	Bar	1" x 2" x 32"	Fansteel	111-D-1102	01-0015-00-B	None	No	Failed ultrasonic inspection.
	02A-078	Bar	1" x 2" x 63"	Fansteel	111-D-1765	01-0015-00-B	None	Yes	
Mo-TZC	02A-037-(1-3)	Rod	1.0" diameter x 14.75"	Climax	4331	01-0011-01-C	Tensile & stress rupture tests for information only - no radiographic inspection.	Yes	
	02A-036-(1-3)	Rod	2.0" diameter x 16.187"	Climax	4331	01-0011-01-C		Yes	
	02A-035-(1-5)	Bar	0.750" x 0.750" x 7"	GE-LMCD	M96	01-0011-01-C	Tensile & stress rupture tests for information only - no radiographic inspection. Start-ingots Ti 1.15-1.55%, Zr 0.13-0.23%, C 0.10-0.15%, W 0.15% max.	No	High tungsten (118 ppm)
	02A-032-(1-6)	Bar	1.375" x 2" x 5"	GE-LMCD	M97	01-0011-01-C		Yes	
	02A-033	Bar	1.375" x 2" x 5"	GE-LMCD	M92	01-0011-01-C		Yes	
Mo-TZM	02A-004	Rod	0.125" diameter x 36"	Climax	5960	CMX-WB-TZM-2	None	Yes	
	02A-005	Rod	0.500" diameter x 36"	Climax	7468	CMX-WB-TZM-2	None	Yes	
	02A-072	Rod	0.500" diameter x 18"	Climax	7498	CMX-WB-TZM-2	None	Yes	
	02A-006	Rod	0.875" diameter x 16"	Climax	7473	CMX-WB-TZM-2	None	Yes	
	02A-071	Rod	0.875" diameter x 24"	Climax	7876	CMX-WB-TZM-2	None	Yes	
	02A-081	Rod	0.875" diameter x 12"	Climax	7876	CMX-WB-TZM-2	None	Yes	
	02A-007	Rod	2.0" diameter x 24"	Climax	7555	CMX-WB-TZM-2	None	Yes	
	02A-070	Rod	2.125" diameter x 12"	Climax	7893	CMX-WB-TZM-2	None	Yes	
Cb-132M	02A-055-(1-3)	Rod	1.0" diameter x 22"	Universal Cyclops	66-95119	01-0010-01-A	None	Yes	
	02A-041-(1-2)	Rod	2.0" diameter x 24"	Universal Cyclops	66-95119	01-0010-01-A	None	No	Elongation & ultimate tensile strength below minimum.
Cb-1Zr	02A-001	Foil	0.002" x 0.5" x 30 lbs	Kawecki	5818	01-0003-03-B	None	Yes	
	02A-002	Foil	0.002" x 3.5" x 10 lbs	Kawecki	5818	01-0003-03-B	None	Yes	

TABLE II. (Cont.)

Alloy	Number	Mill Product Form	Mill Product Size	Vendor	Heat Number	Specifications Number	Specifications Major Exceptions	Meets All Specification Requirements	Remarks
Cb-1Zr	02A-003	Foil	0.005" x 8.0" x 15 lbs	Kawecki	5818	01-0003-03-B	None	Yes	
	02A-022-(1-6)	Sheet	0.0175" x 12" x 24"	Wah Chang	912-70112	01-0003-04-B	Calibration notch of 0.001" deep	Yes	
	02A-034-(1-2)	Sheet	0.030" x 24" x 32"	Wah Chang	912-70112	01-0003-04-B	None	Yes	
	02A-023	Sheet	0.125" x 4" x 12"	Wah Chang	912-70112	01-0003-04-B	None	Yes	
	02A-019	Sheet	0.250" x 6" x 36"	Wah Chang	912-70112	01-0003-04-B	None	Yes	
	02A-050	Tube	0.250" OD x 0.062" wall x 60"	Wah Chang	70303	01-0004-01-D	None	No	Failed ultrasonic inspection.
	02A-040-(1-2)	Tube	0.5" OD x 0.040" wall x 3'-5'	Kawecki	5886	01-0004-01-C	None	No	Failed ultrasonic inspection.
	02A-029	Tube	2.75" OD x 0.125" wall x 48"	Kawecki	5886	01-0004-03-B	None	No	Failed ultrasonic inspection; High Fe (90 ppm).
	02A-030	Wire	0.062" diameter x 2 lbs	Kawecki	5868	01-0003-03-B	None	No	High Ta(1340 ppm), High Fe(60 ppm)
	02A-031	Wire	0.094" diameter x 3 lbs	Kawecki	5868	01-0003-03-B	None	No	High Ta(1340 ppm), High Fe(60 ppm)
	02A-069	Rod	0.250" diameter x 60"	Kawecki	6075	01-0052-01-D	None	Yes	
	02A-020-(1-2)	Rod	0.5" diameter x 120"	Wah Chang	911-53002	01-0003-04-B	None	Yes	
	02A-024	Rod	0.5" diameter x 120"	Wah Chang	911-70559	01-0003-04-B	None	Yes	
	02A-026	Rod	0.625" diameter x 12"	Wah Chang	911-70559	01-0003-04-B	None	Yes	
	02A-025	Rod	1.25" diameter x 24"	Wah Chang	912-900	01-0003-04-B	None	Yes	
Ta	02A-049-(1-8)	Foil	0.002" x 0.5" x 4 lbs	Fansteel	CG-117	B364-62T	H - 10 ppm Max.	Yes	
	02A-012	Sheet	0.032" x 0.75" x 12"	Un.Carbide	81274	B364-61T	H - 15 ppm Max.	Yes	
	02A-011	Sheet	0.062" x 2.125" x 36"	Un.Carbide	81310	B364-61T	H - 15 ppm Max.	Yes	
	02A-013-(1-2)	Bar	0.250" x 4.0" x 72"	Un.Carbide	81371	B364-61T	H - 15 ppm Max.	Yes	
	02A-021	Bar	0.5" x 0.5" x 3'	Un.Carbide	81303	B365-62T	H - 10 ppm max.	Yes	
	02A-016	Bar	0.500" x 1.00" x 28"	Un.Carbide	81259	B364-61T	H - 15 ppm Max.	Yes	
	02A-015	Bar	1.00" x 1.00" x 15"	Un.Carbide	81259	B364-61T	H - 15 ppm Max.	Yes	
	02A-008	Wire	0.020" diameter x 600'	Un.Carbide	81259	B365-61T	H - 15 ppm Max.	Yes	

TABLE II. (Cont.)

Alloy	Number	Mill Product Form	Mill Product Size	Vendor	Heat Number	Specifications Number	Specifications Major Exceptions	Meets All Specification Requirements	Remarks
Ta	02A-009	Rod	0.250" diameter x 24"	Un.Carbide	81303	B365-61T	H - 15 ppm Max.	Yes	
	02A-010	Rod	0.625" diameter x 12"	Un.Carbide	81341	B365-61T	H - 15 ppm Max	Yes	
	02A-014	Rod	1.250" diameter x 8"	Un.Carbide	81259	B365-61T	None	Yes	
T-222	02A-027	Sheet	0.009" x 3.5" x 6.5"	Westinghouse	Ta-39-3	Best Effort			

(1) Material not used in loop fabrication.

(2) After an additional 3000°F/1-hour anneal material passed stress rupture requirements.

TABLE III. CHEMICAL ANALYSIS OF REFRACTORY ALLOY MILL PRODUCTS

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Sample Source	Analyzed By	Chemical Analyses, ppm C	O	N	H	Other (%) W	Hf
T-111	SPECIFICATION 01-0043-00-A						Max 75	Max 300	Max 100	Max 10	Max 9.0	Max 2.4
	02B-011	Foil	0.005" x 3.5" x 52"	111-D-1632	Ingot	Vendor	10[2]	25[2]	20[2]	5[2]	7.79[1]	2.38[1]
					Extruded Bar	Vendor	11[2]	15[2]	21[2]	4[2]	7.73[2]	2.21[2]
					Final Product	Vendor	12	41	20	5.2	---	---
	02A-042	Foil	0.005" x 3.5" x 52"	111-D-1670	Ingot	Vendor	10[2]	72[2]	20[2]	5[2]	7.70[3]	2.17[3]
					Extruded Bar	Vendor	29[2]	30[2]	16[2]	7[2]	7.64[2]	2.37[2]
					Final Product	Vendor	40[1]	62	21	1	---	---
					Final Product	GE	55[1]	114[1]	7	1	---	---
	02A-064	Foil	0.005" x 3.5" x 52"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40[1]	110[1]	9[1]	2.6[1]	---	---
					Final Product	GE	60[1]	150[1]	10[1]	1.5[1]	---	---
	02B-012	Foil	0.009" x 3.5" x 12"	111-D-1632	Ingot	Vendor	10[2]	25[2]	20[2]	5[2]	7.79[1]	2.38[1]
					Extruded Bar	Vendor	11[2]	15[2]	21[2]	4[2]	7.73[2]	2.21[2]
					Final Product	Vendor	---	---	---	---	---	---
					Final Product	GE	45[1]	238	12	3	---	---
	02A-043	Foil	0.009" x 3.5" x 12"	111-D-1670	Ingot	Vendor	10[2]	72[2]	20[2]	5[2]	---	---
					Extruded Bar	Vendor	29[2]	30[2]	16[2]	7[2]	---	---
					Final Product	Vendor	40[1]	61	15	1	---	---
					Final Product	GE	35[1]	141[1]	7[1]	2[1]	---	---
	02A-063-(1-2)	Foil	0.009" x 3.5" x 12"	65076	Ingot	Vendor	<40[3]	50[1]	14[1]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	40[1]	<50[1]	32[1]	2.7[1]	---	---
					Final Product	GE	52[1]	249[1]	8[1]	1[1]	---	---
	SPECIFICATION 01-0040-00-B						Max 50	Max 150	Max 75	Max 10	Max 9.0	Max 2.4
	02A-065-(1-3)	Sheet	0.035" x 1" x 14"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40[1]	100	20	2.6	---	---
					Final Product	GE	41[1]	79	4	1	---	---
	02B-010-(1-2)	Sheet	0.040" x 12" x 50"	111-D-1632	Ingot	Vendor	10[2]	25[2]	20[2]	5[2]	7.79[1]	2.38[1]
					Extruded Bar	Vendor	11[2]	15[2]	21[2]	4[2]	7.73[2]	2.21[2]
					Final Product	Vendor	14[1]	34	17	5	---	---
					Final Product	GE	10[1]	89[1]	9[1]	1[1]	---	---
	02A-057	Sheet	0.125" x 6" x 10"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	80	60	12	2.6	---	---
	02B-009	Plate	0.500" x 6.125" x 11"	111-D-1632	Ingot	Vendor	10[2]	25[2]	20[2]	5[2]	7.79[1]	2.38[1]
					Extruded Bar	Vendor	11[2]	15[2]	21[2]	4[2]	7.73	2.21
					Final Product	Vendor	10[3]	10[1]	20[3]	9.3[1]	---	---
	02A-056	Plate	0.500" x 6.125" x 11"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40[1]	<50[1]	20[1]	2.2[1]	---	---
					Final Product	GE	24[1]	9[1]	3[1]	8[1]	---	---
	SPECIFICATION 01-0035-00-B						Max 50	Max 150	Max 75	Max 10	Max 9.0	Max 2.4
	02A-066-(1-3)	Tube	0.375" OD x 0.065" wall x 144"	111-D-1670	Ingot	Vendor	10[2]	72[2]	20[2]	5[2]	7.70[3]	2.17[3]
					Extruded Bar	Vendor	29[2]	20[2]	16[2]	7[2]	7.65[2]	2.37[2]
					Final Product	Vendor	43	43	16	2	---	---
	02A-067-(1-18)	Tube	0.375" OD x 0.065" wall x 72"	111-D-1670	Ingot	Vendor	10[2]	72[2]	20[2]	5[2]	7.70[3]	2.17[3]
					Extruded Bar	Vendor	29[2]	20[2]	16[2]	7[2]	7.65[2]	2.37[2]
					Final Product	Vendor	43	43	16	2	---	---
					Final Product	GE	25[2]	46[2]	5[2]	3[2]	---	---

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TABLE III. (Cont'd)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Sample Source	Analyzed By	Chemical Analyses, ppm C	O	N	H	Other (%) W	Hf
							Max 50	Max 150	Max 75	Max 10	Max 9.0	Max 2.4
T-111	02A-068-(1-2)	Tube	1.0" OD x 0.100" wall x 140"	111-D-1670	Ingot	Vendor	10	72[2]	20[2]	5[2]	7.70[3]	2.17[3]
					Extruded Bar	Vendor	29[2]	20[2]	16[2]	7[2]	7.65[2]	2.37[2]
					Final Product	Vendor	40[2]	37[2]	22[2]	2[2]	---	---
					Final Product	GE	51[2]	50[2]	4[2]	2[2]	---	---
	02A-074	Tube	1.0" OD x 0.100" wall x 112"	111-D-1670	Ingot	Vendor	10	72[2]	20[2]	5[2]	7.70[3]	2.17[3]
					Extruded Bar	Vendor	29[2]	20[2]	16[2]	7[2]	7.65[2]	2.37[2]
					Final Product	Vendor	23[1]	24[1]	45[1]	5[1]	---	---
					Final Product	GE	22[1]	26[1]	< 1[1]	6[1]	---	---
	02A-075-(1-2)	Tube	1.0" OD x 0.100" wall x 9'	111-D-1670	Ingot	Vendor	10[2]	72[2]	20[2]	5[2]	7.70[3]	2.17[3]
					Extruded Bar	Vendor	29[2]	20[2]	16[2]	7[2]	7.65[2]	2.37[2]
					Final Product	Vendor	23	24	45	5	---	---
					Final Product	GE	27[2]	26[2]	5[2]	6[2]	---	---
	02A-079-(1-2)	Tube	2.250" OD x 0.375" wall x 15"	111-D-1765	Ingot	Vendor	10[2]	44[2]	23[2]	5[2]	8.44[2]	1.93[2]
					Final Product	Vendor	22[1]	25[1]	22[1]	5[1]	---	---
					Final Product	GE	15[1]	41[1]	9[1]	5[1]	---	---
	02A-085	Tube	2.5" OD x 1.610" ID x 13"	111-D-1829	Ingot	Vendor	34	32	19	5	5.75	2.31
					Final Product	Vendor	10	20	33	5	---	---
					Final Product	GE	20[2]	15[2]	2[2]	2[2]	---	---
	02A-080	Tube	2.50" OD x 1.610" ID x 13"	111-D-1765	Ingot	Vendor	10[2]	44[2]	23[2]	5[2]	8.44[2]	1.93[2]
					Final Product	Vendor	22	25	22	5	---	---
	02A-046-(1-2)	Tube	3.0" OD x 0.375" wall x 13"	111-D-1102	Ingot	Vendor	10	53	20	5	7.97[1]	2.40[1]
					Finished Product	GE	22	58	8	6	---	---
	02A-048	Tube	3.25" OD x 0.250" wall x 14"	111-D-1102	Ingot	Vendor	10[2]	53[2]	20[2]	5[2]	7.97[1]	2.40[1]
					Extruded Bar	Vendor	20[2]	51[2]	21[2]	3[2]	7.94[2]	2.28[2]
					Final Product	Vendor	34[1]	20[1]	13[1]	3.3[1]	---	---
					Final Product	GE	20[1]	58[1]	9[1]	6[1]	---	---
	02A-045	Tube	3.25" OD x 0.500" wall x 14"	111-D-1102	Ingot	Vendor	10[2]	53[2]	20[2]	5[2]	7.97[1]	2.40[1]
					Extruded Bar	Vendor	20[2]	51[2]	21[2]	3[2]	7.94[2]	2.28[2]
					Final Product	Vendor	34[1]	20[1]	13[1]	3.3[1]	---	---
					Final Product	GE	20[1]	58[1]	9[1]	6[1]	---	---
	02A-086	Tube	3.25" OD x 0.25" wall x 14"	111-D-1829	Ingot	Vendor	34	32	19	5	5.75	2.31
					Final Product	Vendor	10	20	29	5	---	---
	02A-087	Tube	3.25" OD x 0.50" wall x 14"	111-D-1829	Ingot	Vendor	34	32	19	5	5.75	2.31
					Final Product	Vendor	10	20	29	5	---	---
					Final Product	GE	29	10	1	2	---	---
							Max 50	Max 150	Max 75	Max 10	Max 9.0	Max 2.4
	SPECIFICATION 01-0048-00-A											
	02B-001	Wire	0.062" diameter x 6 lbs	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24
					Finished Product	Vendor	42[1]	110	22	1	---	---
					Finished Product	GE	23[1]	126[1]	6[1]	1[1]	8.16[1]	2.53[1]
	02A-039-(1-2)	Wire	0.062" diameter x 6.47 lbs	70616	Ingot	Vendor	20[1]	<50[1]	14[1]	2.8[1]	8.0[1]	1.83[1]
					Finished Product	Vendor	60	<50	< 5	1.2	---	---

TABLE III. (Cont'd)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Sample Source	Analyzed By	Chemical Analyses, ppm C	O	N	H	Other (%) W	Hf
							Max 50	Max 150	Max 75	Max 10	Max 9.0	Max 2.4
T-111	02B-002	Wire	0.094" diameter x 8 lbs	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Finished Product	Vendor	43[1]	111	20	< 1	---	---
					Finished Product	GE	16[1]	57	3	1	8.49[1]	2.60[1]
	02B-003	Wire	0.125" diameter x 168'	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Finished Product	Vendor	33[1]	69	21	< 1	---	---
					Finished Product	GE	18[1]	68[1]	5[1]	1[1]	8.41[1]	2.73[1]
	02A-059	Wire	0.125" diameter x 40'	70616	Ingot	Vendor	20[1]	<50[1]	14[1]	2.8[1]	8.00[1]	1.83[1]
					Finished Product	Vendor	<40[1]	<50[1]	20[1]	1.3[1]	---	---
					Finished Product	GE	29[1]	6[1]	1[3]	1[1]	---	---
	02A-060	Wire	0.125" diameter x 7.9 lbs	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Finished Product	Vendor	60[1]	<50[1]	15[1]	2.6[1]	---	---
					Finished Product	GE	36[1]	46[1]	5[1]	1[1]	---	---
	02A-073	Wire	0.125" diameter x 4.4 lbs	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Finished Product	Vendor	60	<50	15	2.6	---	---
	SPECIFICATION 01-0015-00-B						Max 50	Max 150	Max 75	Max 10	Max 9.0	Max 2.4
	02B-004	Rod	0.250" diameter x 24"	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Finished Product	Vendor	13[1]	15	23	< 1	---	---
					Finished Product	GE	25[1]	77[1]	11[1]	2[1]	---	---
	02A-054	Rod	0.250" diameter x 24"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	40	<50[1]	12[1]	2.7[1]	---	---
					Final Product	GE	NP	21[1]	3[1]	1[1]	---	---
	02B-005	Rod	0.500" diameter x 48"	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Finished Product	Vendor	17[3]	30[1]	20[3]	< 1[1]	---	---
	02A-052	Rod	0.500" diameter x 48"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40[1]	130[1]	12[1]	1.8	---	---
					Final Product	GE	27[1]	14[1]	3[1]	< 1	---	---
	02B-006	Rod	0.625" diameter x 14"	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Finished Product	Vendor	17[3]	30[1]	20[3]	< 1[1]	---	---
	02A-053	Rod	0.625" diameter x 14"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40[1]	130[1]	12[1]	1.8	---	---
					Final Product	GE	23[1]	13[1]	5[1]	< 1	---	---
	02B-007-(1-2)	Rod	1.0" diameter x 42"	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Finished Product	Vendor	9[3]	11[1]	24[3]	1[1]	---	---
	02A-062	Rod	1.0" diameter x 42"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40[1]	<50[1]	17[1]	3.7[1]	---	---
					Final Product	GE	24[1]	17[1]	5[1]	9[1]	---	---

TABLE III. (Cont'd)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Sample Source	Analyzed By	Chemical Analyses, ppm C	O	N	H	Other (%) W	Hf
							Max	Max	Max	Max	Max	Max
							50	150	75	10	9.0	2.4
T-111	02B-008	Rod	1.125" diameter x 8"	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Finished Product	Vendor	9[3]	11[1]	24[3]	1[1]	---	---
	02A-061	Rod	1.125" diameter x 8"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40[1]	<50[1]	17[1]	3.7[1]	---	---
					Final Product	GE	26[1]	19[1]	5[1]	11[1]	---	---
	02B-014	Rod	1.5" diameter x 6"	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Final Product	Vendor	25[1]	28	48	1	---	---
					Final Product	GE	15[1]	48[1]	10[3]	3[1]	---	---
	02A-058	Rod	1.50" diameter x 6"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40[1]	120[1]	15[1]	3.4[1]	---	---
					Final Product	GE	8[1]	14[1]	3[1]	15[1]	6.91[1]	2.06[1]
	02A-044-(1-3)	Rod	2.0" diameter x 21"	111-D-1102	Ingot	Vendor	10[2]	53[2]	20[2]	5[2]	7.97[2]	2.4[2]
					Extruded Bar	Vendor	20[2]	51[2]	21[2]	3[2]	7.94[2]	2.28[2]
					Final Product	Vendor	20[1]	73[1]	26[1]	3.7[1]	---	---
					Final Product	GE	26[1]	43[1]	7[1]	4[1]	---	---
	02A-082	Rod	2.0" diameter x 24"	111-D-1829	Ingot	Vendor	34[2]	33[2]	19[2]	5[2]	7.50[2]	2.31[2]
					Final Product	Vendor	10[1]	20[1]	33[1]	5[1]	---	---
					Final Product	GE	25[1]	17[1]	3[1]	5[1]	---	---
	02A-038	Rod	2.5" diameter x 21 1/16"	111-D-1670	Ingot	Vendor	10[2]	72[2]	20[2]	5[2]	7.70[3]	2.17[3]
					Extruded Bar	Vendor	29[2]	20[2]	16[2]	7[2]	7.05[2]	2.37[2]
					Final Product	Vendor	26[1]	30[1]	31[1]	2[1]	---	---
					Final Product	GE	23[1]	33[1]	4[1]	8[1]	---	---
	02A-077	Rod	2.5" diameter x 5.188"	111-D-1765	Ingot	Vendor	10[2]	44[2]	23[2]	6[2]	8.44[2]	1.93[2]
					Final Product	Vendor	22	25	22	5	---	---
					Final Product	GE	14[2]	23[2]	19[2]	2[2]	---[2]	---[2]
	02A-083	Rod	2.5" diameter x 5"	111-D-1829	Ingot	Vendor	34[2]	33[2]	19[2]	5[2]	7.5[2]	2.3[2]
					Final Product	Vendor	10[2]	20[2]	33[2]	5[2]	---	---
	02A-076	Rod	3.125" diameter x 16"	111-D-1765	Ingot	Vendor	10[2]	44[2]	23[2]	6[2]	8.44[2]	1.93[2]
					Final Product	Vendor	40[1]	10[1]	19[1]	5[1]	---	---
					Final Product	GE	15[1]	55[1]	21[1]	6[1]	---	---
	02B-013-(1-3)	Bar	1" x 1" x 12.5"	111-D-1633	Ingot	Vendor	10	25	10	10	7.74[1]	2.23[1]
					Extruded Bar	Vendor	17	19	16	6	7.80[2]	2.24[2]
					Final Product	Vendor	25[1]	28	48	1	---	---
					Final Product	GE	15[1]	53[1]	6[3]	3[1]	---	---
	02A-051	Bar	1" x 1" x 12.5"	65076	Ingot	Vendor	<40[3]	50[1]	14[3]	2.8[1]	8.60[3]	1.93[3]
					Final Product	Vendor	<40	120[1]	15[1]	3.4	---	---
					Final Product	GE	NP	148[1]	8[1]	< 1	---	---
	02A-047	Bar	1" x 2" x 32"	111-D-1102	Ingot	Vendor	10[2]	53[2]	20[2]	5[2]	7.97[1]	2.40[1]
					Extruded Bar	Vendor	20[2]	51[2]	21[2]	3[2]	7.94[2]	2.30[2]
					Final Product	Vendor	42[1]	55	18	4.7	---	---
					Final Product	GE	40[1]	58	12[2]	2[2]	---	---
	02A-078	Bar	1" x 2" x 63"	111-D-1765	Ingot	Vendor	10[2]	44[1]	23[2]	6[2]	8.44[2]	1.65[2]
					Final Product	Vendor	40[1]	28[1]	34[1]	5[1]	---	---
					Final Product	GE	18[1]	36[1]	15[1]	6[1]	---	---

TABLE III. (Cont'd)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Sample Source	Analyzed By	Chemical Analyses, ppm C	O	N	H	Other (%) Ti	Other (%) Zr
Mo-TZC	SPECIFICATION 01-0011-00-C						Max	Max	Max	Max	Max	Max
							1400	20	10	5	1.3	0.18
	02A-037-(1-3)	Rod	1.0" diameter x 14.75"	4331	Final Product	Vendor	1300[2]	4	< 1	< 1	1.20[2]	0.17[2]
					Final Product	GE	1350[1]	15	8	3	---	---
	02A-036-(1-3)	Rod	2.0" diameter x 16.187"	4331	Final Product	Vendor	1300[2]	4	2	< 1	1.20[2]	0.17[2]
					Final Product	GE	1220[1]	11[1]	4[1]	2[1]	---	---
	02A-035-(1-5)	Bar	0.750" x 0.750" x 7"	M96	Final Product	Vendor	1309[1]	6[1]	3[1]	2[1]	1.40[1]	0.21[1]
					Final Product	GE	1140[1]	20[1]	4[1]	3[1]	---	---
	02A-032-(1-6)	Bar	1.375" x 2" x 5"	M97	Final Product	Vendor	1163[1]	5[1]	2[1]	2[1]	1.35[1]	0.19[1]
					Final Product	GE	1140[1]	24[1]	2[1]	1[1]	---	---
	02A-033	Bar	1.375" x 2" x 5"	M92	Final Product	Vendor	1171[1]	3[1]	3[1]	2[1]	1.35[1]	0.20[1]
					Final Product	GE	700[1]	98	4	< 1	---	---
Mo-TZM	SPECIFICATION CMX-WB-TZM-2						Max	Max	Max	Max	Max	Max
							300	25	20	5	0.55	0.12
	02A-004	Rod	0.125" diameter x 36"	5960	Final Product	Vendor	140	<10	< 3	< 1	0.55	0.08
	02A-005	Rod	0.500" diameter x 36"	7468	Final Product	GE	108[1]	11	2	< 1	---	---
					Final Product	Vendor	220	< 4	1	< 1	0.50	0.09
	02A-072	Rod	0.500" diameter x 18"	7498	Final Product	Vendor	160	4	1	< 1	0.54	0.09
	02A-006	Rod	0.875" diameter x 16"	7473	Final Product	Vendor	160[1]	2[1]	< 1[1]	< 1	0.50	0.09
					Final Product	GE	104[1]	9[1]	3[1]	< 1	---	---
	02A-071	Rod	0.875" diameter x 24"	7876	Final Product	Vendor	160	< 4	1	< 1	0.49	0.105
	02A-081	Rod	0.875" diameter x 12"	7876	Final Product	Vendor	160[1]	< 4[1]	1[1]	< 1[1]	0.49	0.105
					Final Product	GE	176[1]	5[1]	7[1]	< 1[1]	---	---
	02A-007	Rod	2.0" diameter x 24"	7555	Final Product	Vendor	210[1]	< 4[1]	< 1[1]	< 1	0.49	0.10
					Final Product	GE	184[1]	5[1]	1[1]	1	---	---
	02A-070	Rod	0.125" diameter x 12"	7893	Final Product	Vendor	180	14	2	1	0.44	0.11
Cb-132M	SPECIFICATION 01-0010-01-A						Max	Max	Max	Max	Max	Max
							1500	200	100	10	Mo-5.5	W-16.5
											Ta-21.5[2]	Zr-2.25[2]
	02A-055-(1-3)	Rod	1.0" diameter x 22"	66-95119	Ingot	Vendor	1375[2]	55[2]	33[2]	2.3[2]	Mo-4.95[2]	W-14.5[2]
											Ta-19.79[2]	Zr-2.0[2]
					Final Product	Vendor	1300[1]	24[1]	34[1]	4[1]	---	---
					Final Product	GE	1350[2]	14[1]	6[1]	1[1]	---	---
	02A-041-(1-2)	Rod	2.0" diameter x 24"	66-95119	Ingot	Vendor	1375[2]	55[2]	33[2]	2.3[2]	Mo-4.95[2]	W-14.5[2]
											Ta-19.79[2]	Zr-2.0[2]
					Final Product	Vendor	1220[1]	27[1]	79[3]	3.7[1]	---	---
					Final Product	GE	1300[1]	28[3]	18[3]	17[3]	---	---
Cb-1Zr	SPECIFICATION 01-0003-03-B						Max	Max	Max	Max	Zr	
							100	300	300	10	0.8-1.2	
	02A-001	Foil	0.002" x 0.5" x 30 lbs	5818	Ingot	Vendor	40	70	30	2.1	1.1	
					Final Product	Vendor	50	60	30	2.3	---	
	02A-002	Foil	0.002" x 3.5" x 10 lbs	5818	Ingot	Vendor	40	70	30	2.1	1.1	
					Final Product	Vendor	50	60	30	2.3	---	
	02A-003	Foil	0.005" x 8.0" x 15 lbs	5818	Ingot	Vendor	40	70	30	2.1	1.1	
					Final Product	Vendor	50	60	30	2.3	---	
	SPECIFICATION 01-0003-04-B						Max	Max	Max	Max	Zr	
							100	300	300[2]	10[1]	0.8-1.2[2]	
	02A-022-(1-6)	Sheet	0.0175" x 12" x 24"	912-70112	Ingot	Vendor	42	210	63	3.7	1.02	
					Final Product	Vendor	70	180	50	7	---	
					Final Product	GE	48[1]	110[1]	28[1]	3	---	

TABLE III. (Cont'd)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Sample Source	Analyzed By	Chemical Analyses, ppm C	O	N	H	Other (%)
							Max	Max	Max	Max	Zr
Cb-1Zr	02A-034-(1-2)	Sheet	0.030" x 24" x 32"	912-70112	Ingot	Vendor	100 / 32[2]	300 / 130	300 / 65[2]	10 / 4.5[1]	0.8-1.2 / 1.03[2]
					Final Product	Vendor	<30[1]	130[1]	35[1]	6	---
					Final Product	GE	25[2]	121[1]	60[2]	< 1[1]	---[2]
	02A-023	Sheet	0.125" x 4" x 12"	912-70112	Ingot	Vendor	42[2]	210	63[2]	3.7[1]	1.02[2]
					Final Product	Vendor	30[1]	130[1]	52[1]	3.1[1]	---
					Final Product	GE	45[2]	132[1]	27[1]	< 1[1]	---[2]
	02A-019	Sheet	0.250" x 6" x 36"	912-70112	Ingot	Vendor	42[2]	210	63[2]	3.7[1]	1.02[2]
					Final Product	Vendor	<30[1]	<50[1]	58[1]	4.1	---
					Final Product	GE	30[1]	71[1]	22[1]	< 1	---
	SPECIFICATION 01-0004-01-D						Max	Max	Max	Max	Zr
	02A-050	Tube	0.250" OD x 0.062" wall x 60"	70303	Ingot	Vendor	200 / 42[1]	300 / 260[1]	100 / 55[1]	10 / 3.5[1]	0.8-1.2 / 0.97
					Final Product	Vendor	<40[1]	140	65	5.1	---
					Final Product	GE	75[1]	211	63	3	---
	SPECIFICATION 01-0004-01-C						Max	Max	Max	Max	Zr
	02A-040-(1-2)	Tube	0.5" OD x 0.040" wall x 3'-5'	5886	Ingot	Vendor	200 / 40[2]	300 / 70[2]	100 / 30[2]	10 / 2.1[2]	0.8-1.2 / 1.1[2]
					Final Product	Vendor	35[1]	60	40	2.4	---
					Final Product	GE	87[1]	84	13	4	---
	SPECIFICATION 01-0004-03-B						Max	Max	Max	Max	Zr
	02A-029	Tube	2.75" OD x 0.125" wall x 48"	5886	Final Product	Vendor	100 / 40[1]	300 / 70[1]	300 / 40[1]	10 / 2	0.8-1.2 / 1.1
					Final Product	GE	43[1]	97[1]	6[1]	1	---
	SPECIFICATION 01-0003-03-B						Max	Max	Max	Max	Zr
	02A-030	Wire	0.062" diameter x 2 lbs	5868	Ingot	Vendor	100 / <100	300 / 60	300 / 50	10 / 5	0.8-1.2 / 1.08
					Final Product	Vendor	80	50	40	5	---
	02A-031	Wire	0.094" diameter x 3 lbs	5868	Ingot	Vendor	<100	60	50	5	1.08
					Final Product	Vendor	80	50	40	5	---
	SPECIFICATION 01-0052-01-C						Max	Max	Max	Max	Zr
	02A-069	Rod	0.250" diameter x 60"	6075	Final Product	Vendor	200 / 40	300 / 70	100 / <10	10 / 1.8	0.8-1.2 / 1.1
	SPECIFICATION 01-0003-04-B						Max	Max	Max	Max	Zr
	02A-020-(1-2)	Rod	0.5" diameter x 120"	911-53002	Ingot	Vendor	100 / 54[2]	300 / 125[1]	300 / 42[2]	10 / 3.9[1]	0.8-1.2 / 0.93[2]
					Final Product	Vendor	40[1]	130[1]	50[1]	2.7	---
					Final Product	GE	20[1]	122[1]	27[1]	< 1[1]	---[1]
	02A-024	Rod	0.5" diameter x 120"	911-70559	Ingot	Vendor	30[1]	165[1]	55[1]	4.9[1]	0.91[1]
					Final Product	Vendor	<30[1]	148[1]	30[1]	1.9	---
					Final Product	GE	32[1]	156[1]	35[1]	< 1[1]	---[2]
	02A-026	Rod	0.625" diameter x 12"	911-70559	Ingot	Vendor	33[3]	165[1]	60[3]	4.9[1]	0.95[2]
					Final Product	Vendor	40[1]	120[1]	45[1]	2.6	---
					Final Product	GE	42[1]	145[1]	31[1]	< 1[1]	---[2]
	02A-025	Rod	1.25" diameter x 24"	912-900	Ingot	Vendor	31[2]	285[1]	97[2]	2.2[1]	1.08[2]
					Final Product	Vendor	50	200	45	4.3	---
					Final Product	GE	114	248	61	7	---

TABLE III. (Cont'd)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Sample Source	Analyzed By	Chemical Analyses, ppm C	O	N	H	Other (%)
Ta	SPECIFICATION ASTM-B364-62T										
							Max 300	Max 300	Max 150	Max 10	
	02A-049-(1-8)	Foil	0.002" x 0.5" x 4 lbs	CG-117	Final Product	Vendor	10	28	28	5	Zr-5
	SPECIFICATION ASTM-B364-61T										
							Max 300	Max 300	Max 150	Max 15	
	02A-012	Sheet	0.032" x 0.75" x 12"	81274	Final Product	Vendor	10	12	5	3	---
					Final Product	GE	4[1]	8[1]	5[1]	< 1	---
	02A-011	Sheet	0.062" x 2.125" x 36"	81310	Final Product	Vendor	50	22	17	8	---
					Final Product	GE	6[1]	16[1]	11[1]	< 1	---
	02A-013-(1-2)	Bar	0.250" x 4.0" x 72"	81371	Final Product	Vendor	29	45	10	1	---
					Final Product	GE	12[1]	12[1]	2[1]	1[1]	---
	SPECIFICATION ASTM-B-365-62T										
							Max 300	Max 300	Max 150	Max 10	
	02A-021	Bar	0.5" x 0.5" x 3'	81303	Final Product	Vendor	<10	24	12	3	---
	SPECIFICATION ASTM-B-364-61T										
							Max 300	Max 300	Max 150	Max 15	
	02A-016	Bar	0.500" x 1.00" x 28"	81259	Final Product	Vendor	<10[1]	6[1]	10[1]	3	---
					Final Product	GE	10[1]	37[1]	10[1]	< 1	---
	02A-015	Bar	1.00" x 1.00" x 15"	81259	Final Product	Vendor	10[1]	6[1]	10[1]	3	---
					Final Product	GE	3[1]	12[1]	5[1]	< 1	---
	SPECIFICATION ASTM-B-365-62T										
							Max 300	Max 300	Max 150	Max 15	
	02A-008	Wire	0.020" diameter x 600'	81259	Final Product	Vendor	<10	6	10	3	---
	02A-009	Rod	0.250" diameter x 24"	81303	Final Product	Vendor	<10[1]	24[1]	12[1]	3[1]	---
					Final Product	GE	17[1]	52[1]	20[1]	< 1[1]	---
	02A-010	Rod	0.625" diameter x 12"	81341	Final Product	Vendor	<10	6	2	3	---
					Final Product	GE	18[1]	19[1]	12[1]	1[1]	---
	02A-014	Rod	1.250" diameter x 8"	81259	Final Product	Vendor	<10[1]	6	10	3	---
					Final Product	GE	21[1]	20	18	< 1	---
T-222	SPECIFICATION						Best Effort				
	02A-027	Sheet	0.009" x 3.5" x 6.5"	Ta-39-3	Final Product	Vendor	130	18	41	---	W-8.9 Hf-2.2
					Final Product	GE	290	162	28	< 1	---

[1] Average of 2 analyses.

[2] Average of 4 analyses or more.

[3] Average of 3 analyses.

TABLE IV. MECHANICAL PROPERTIES & GRAIN SIZE OF REFRACTORY ALLOY MILL PRODUCTS

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Final Heat Treatment	Room Temperature Tensile Properties Ult. Ksi	0.2%Y.S. Ksi	Elong. %	2400°F Stress-Rupture Life at 19,000 psi Hours	Elong,%	Bend or Flare	Hardness Bulk	Hardness Micro (DPH) Surface	Hardness Micro (DPH) Center	Grain Size Vendor ASTM No.	Grain Size GE ASTM No.	Recrystallization (%) Vendor	Recrystallization (%) GE
T-111	SPECIFICATION	Foil	01-0043-00-A								180°w/No Fail.						100%	
	02B-011	Foil	0.005" x 3.5" x 52"	111-D-1632	1475°C/1 hr.*	-	-	-	-	-	180° Passed	-	-	-	-	-	100	-
	02A-042	Foil	0.005" x 3.5" x 52"	111-D-1670	1475°C/1 hr.	-	-	-	-	-	180° Passed	-	-	-	-	8	95	100
	02A-064	Foil	0.009" x 3.5" x 52"	65076	3000°F/1 hr.	-	-	-	-	-	180° Passed	215BHN	-	-	-	6-7	100	100
	02B-012	Foil	0.009" x 3.5" x 12"	111-D-1632	1475°C/1 hr.	-	-	-	-	-	180° Passed	-	-	-	-	8	100	100
	02A-043	Foil	0.009" x 3.5" x 12"	111-D-1670	1475°C/1 hr.	-	-	-	-	-	180° Passed	-	-	-	-	8	95	100
	02A-063-(1-2)	Foil	0.009" x 3.5" x 12"	65076	3000°F/1 hr.	-	-	-	-	-	180° Passed	215BHN	-	-	-	7	100	100
	SPECIFICATION	Sheet, Plate, and Strip - 01-0040-00-B				Max. 110	Max. 100	Min. 20	Min. 20		105°w/No Fail.		Max. 50 Variance		6		100	
	02A-065-(1-3)	Sheet	0.035" x 1" x 14"	65076	3000°F/1 hr.	79.9[1]	93.2[1]	31[1]	>20[1]	-	180° Passed	215BHN	275	249	7½	6	100	100
	02B-010-(1-2)	Sheet	0.040" x 12" x 50"	111-D-1632	1475°C/1 hr.	91.6[1]	82.6[1]	30.5[1]	15.9[1]	-	135° Passed	-	226	223	7½	8	100	100
	02A-057	Sheet	0.125" x 6" x 10"	65076	3000°F/1 hr.	92.9[1]	77.9[1]	36.5[1]	>20[1]	-	105° Passed	215BHN	257	226	7-7½	-	100	-
	02B-009	Plate	0.500" x 6.125" x 11"	111-D-1632	1475°C/1 hr.	91.5[1]	77.7[1]	42.5[1]	12.6[1]	-	-	-	245	213	6½	-	100	-
	02A-056	Plate	0.500" x 6.125" x 11"	65076	3000°F/1 hr.	90.7[1]	73.1[1]	37.5[1]	>20[1]	-	-	215BHN	251	227	6-6½	4-6	100	100
	SPECIFICATION	Seamless Tubing and Pipe - 01-0035-00-B				Max. 110	Max. 100	Min. 20	Min. 20		Flare - 15% OD Increase		Max. 50 Variance		Min. 5		Min. 100	
	02A-066-(1-3)	Tube	0.375" OD x 0.065" W x 144"	111-D-1670	3000°F/1 hr.	88.3[1]	75.9[1]	32.5[1]	>43[1]	-	-	-	226	219	5½	5	100	100
	02A-067-(1-18)	Tube	0.375" OD x 0.065" W x 72"	111-D-1670	3000°F/1 hr.	88.3[1]	75.9[1]	32.5[1]	>43[1]	-	-	-	226	219	5½	5	100	100
	02A-068-(1-2)	Tube	1.0" OD x 0.100" W x 140"	111-D-1670	3000°F/1 hr.	91.8[1]	74.6[1]	27[1]	>43[1]	-	-	-	226	219	5½	5	100	100
	02A-074	Tube	1.0" OD x 0.100" W x 112"	111-D-1670	3000°F/1 hr.	91.4	74.5	33	38.9[1]	-	-	-	224	217	5	5	100	100
	02A-075-(1-2)	Tube	1.0" OD x 0.100" W x 9'	111-D-1670	3000°F/1 hr.	91.4	74.5	33	38.9[1]	-	-	-	224	217	5	5	100	100
															Min. 3		Min. 90	
	02A-079-(1-2)	Tube	2.250" OD x 0.375" W x 15"	111-D-1765	3000°F/1 hr.	91.5[1]	73.4[1]	34.5[1]	43.5[1]	-	-	-	230	226	5	4	100	100
	02A-085	Tube	2.5" OD x 1.610 ID x 13"	111-D-1829	3000°F/1 hr.	88.5[1]	69.4[1]	42.5[1]	26.6[1]	-	-	-	213	219	5½	6	100	100
	02A-080	Tube	2.50" OD x 1.610" ID x 13"	111-D-1765	3000°F/1 hr.	91.5[1]	73.4[1]	34.5[1]	43.5[1]	-	-	-	230	226	5	-	100	-
	02A-046-(1-2)	Tube	3.0" OD x 0.375" W x 13"	111-D-1102	1475°C/2 hrs.**	86.6[1]	74.1[1]	42[1]	>21[1]	-	-	-	216	213	4-6	3	100	100

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TABLE IV. (Cont'd)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Final Heat Treatment	Room Temperature Tensile Properties Ult. Ksi	0.2%Y.S. Ksi	Elong. %	2400°F Stress-Rupture Life at 19,000 psi Hours	Elong,%	Bend or Flare	Hardness Bulk	Hardness Micro (DPH) Surface	Hardness Micro (DPH) Center	Grain Size Vendor ASTM No.	Grain Size GE ASTM No.	Recrystallization (%) Vendor	Recrystallization (%) GE
T-111	02A-048	Tube	3.25" OD x 0.250" W x 14"	111-D-1102	1475°C/2 hrs.**	86.6[1]	74.1[1]	42[1]	>21[1]	-	-	-	216	213	4-6	4	100	100
	02A-045	Tube	3.25" OD x 0.500" W x 14"	111-D-1102	1475°C/2 hrs.**	86.6[1]	74.1[1]	42[1]	>21[1]	-	-	-	216	213	4-6	4	100	100
	02A-086	Tube	3.25" OD x 0.25" W x 14"	111-D-1829	3000°F/1 hr.	87.6[1]	69.1[1]	32.5[1]	28.1[1]	-	-	-	213	213	4	-	100	-
	02A -087	Tube	3.25" OD x 0.500" W x 14"	111-D-1829	3000°F/1 hr.	87.6[1]	69.1[1]	32.5[1]	28.1[1]	-	-	-	213	213	4	-	100	-
	SPECIFICATION	Wire	01-0048-00-A														100	
	02B-001	Wire	0.062" Ø x 6#	111-D-1633	1475°C/1 hr.	-	-	-	-	-	-	-	-	-	-	6-7	100	100
	02A-039-(1-2)	Wire	0.062" Ø x coil	70616	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	02B-002	Wire	0.094" Ø x 8#	111-D-1633	1475°C/1 hr.	-	-	-	-	-	-	-	-	-	-	6	100	100
	02B-003	Wire	0.125" Ø x 168'	111-D-1633	1475°C/1 hr.	-	-	-	-	-	-	-	-	-	-	6	100	100
	02A-059	Wire	0.125" Ø x 40' (3.1#)	70616	3000°F/1 hr.	-	-	-	-	-	-	215BHN	-	-	-	7	-	100
	02A-060	Wire	0.125" Ø x 7.9#	65076	3000°F/1 hr.	-	-	-	-	-	-	215BHN	-	-	-	5	100	100
	SPECIFICATION	Bar and Rod - 01-0015-00-B				Max. 110	Max. 100	Min. 20	Min. 20				Max. 50 Variance		2		2	
	02B-004	Rod	0.250" Ø x 24"	111-D-1633	1475°C/1 hr.	89.8[1]	76.5[1]	34[1]	13.6[1]	-	-	-	237	234	6½	6	100	100
	02A-054	Rod	0.250" Ø x 24"	65076	3000°F/1 hr.	91.2[1]	76.4[1]	28.5[1]	>20.1[1]	-	-	215BHN	260	238	7½	7	100	100
	02B-005	Rod	0.500" Ø x 48"	111-D-1633	1475°C/1 hr.	89.6[1]	72.7[1]	42.5[1]	16.7[1]	-	-	-	226	216	6½	7	100	100
	02A-052	Rod	0.500" Ø x 48"	65076	3000°F/1 hr.	90.5[1]	72.9[1]	32.5[1]	>20.1[1]	-	-	215BHN	264	237	7½	7	100	100
	02B-006	Rod	0.625" Ø x 14"	111-D-1633	1475°C/1 hr.	89.6[1]	72.7[1]	42.5[1]	16.7[1]	-	-	-	226	216	6½	7	100	100
	02A-053	Rod	0.625" Ø x 14"	65076	3000°F/1 hr.	90.5[1]	72.9[1]	32.5[1]	>20.1[1]	-	-	215BHN	264	237	7½	7	100	100
	02B-007-(1-2)	Rod	1.0" Ø x 42"	111-D-1633	1475°C/1 hr.	83.3[1]	69.7[1]	46.5[1]	14.3[1]	-	-	-	226	207	4-5½	5-6	100	100
	02A-062	Rod	1.0" Ø x 42"	65076	3000°F/1 hr.	92.0[1]	74.0[1]	35[1]	>20.1[1]	-	-	215BHN	252	230	7	5-6	100	100
	02B-008	Rod	1.125" Ø x 8"	111-D-1633	1475°C/1 hr.	83.3[1]	69.7[1]	46.5[1]	14.3[1]	-	-	-	-	-	4-5½	5	100	100
	02A-061	Rod	1.125" Ø x 8"	65076	3000°F/1 hr.	92.0[1]	74.0[1]	35[1]	>20.1[1]	-	-	215BHN	252	230	7	4-6	100	100
	02B-014	Rod	1.5" Ø x 6"	111-D-1633	1475°C/2 hrs.	86.5[1]	75.5[1]	42.5[1]	21.0+[3] 25.0+[3]	-	-	-	201	204	3-7	-	95	0
	02A-058	Rod	1.50"Ø x 6"	65076	3000°F/1 hr.	87.4[1]	71.0[1]	32.5[1]	>20.0[1]	-	-	215BHN	263	226	7	4-6	100	100

TABLE IV. (Cont'd)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Final Heat Treatment	Room Temperature Tensile Properties Ult. Ksi	Room Temperature Tensile Properties 0.2%Y.S. Ksi	Room Temperature Tensile Properties Elong. %	2400°F Stress Rupture Life at 19,000 psi Hours	2400°F Stress Rupture Life at 19,000 psi Elong,%	Bend or Flare	Hardness Bulk	Hardness Micro (DPH) Surface	Hardness Micro (DPH) Center	Grain Size Vendor ASTM No.	Grain Size GE ASTM No.	Recrystallization (%) Vendor	Recrystallization (%) GE
T-111	02A-044-(1-3)	Rod	2.0" Ø x 21"	111-D-1102	1475°C/2 hrs.** +3000°F/1 hr.	86.4[1]	75.4[1]	42.5[1]	16.6[3] 21.5[3]	-	-	-	225	209	4-6	5	100	100
	02A-082	Rod	2.0" Ø x 24"	111-D-1829	3000°F/1 hr.	88.5[1]	69.4[1]	42.5[1]	-	-	-	-	213	219	5½	4½	100	100
	02A-038	Rod	2.5" Ø x 21-1/16"	111-D-1670	1475°C/2 hrs.** 3000°F/1 hr.	84.2[1]	69.9[1]	39.5[1]	9.4[3] 22.8[3]	-	-	-	219	213	5-7	5	100	100
	02A-077	Rod	2.5" Ø x 5.188"	111-D-1765	3000°F/1 hr.	91.5[1]	73.4[1]	34.5[1]	43.5[1]	-	-	-	230	226	5	3½	100	100
	02A-083	Rod	2.5" Ø x 5"	111-D-1829	3000°F/1 hr.	88.5[1]	69.4[1]	42.5	-	-	-	-	213	219	5½	4½	100	100
	02A-076	Rod	3.125" Ø x 16"	111-D-1765	3000°F/1 hr.	93.4[1]	74.8[1]	34[1]	43+[1]	-	-	-	230	226	3-5	4	100	100
	02B-013-(1-3)	Bar	1" x 1" x 12.5"	111-D-1633	1475°C/1 hr.	86.5[1]	75.5[1]	42.5[1]	21.0+[3] 25.0+[3]	-	-	-	201	204	3-7	5	100	100
	02A-051	Bar	1" x 1" x 12.5"	65076	3000°F/1 hr.	87.4[1]	71.0[1]	32.5[1]	>20.0[1]	-	-	215BHN	263	226	7	5	100	100
	02A-047	Bar	1" x 2" x 32"	111-D-1102	1475°C/2 hrs.** 3000°F/1 hr.	89.8[1]	78.0[1]	37.5[1]	>21.5[1]	-	-	-	219	212	6	6	100	100
	02A-078	Bar	1" x 2" x 63"	111-D-1765	3000°F/1 hr.	92.8[1]	75.8[1]	37[1]	43[1]	-	-	-	224	234	4½	5	100	100
	SPECIFICATION	Bar and Rod - 01-0011-00-C				Max. 175	Max. 140	Min. 15	Min. 20								Max. 5	
Mo-TZC	02A-037-(1-3)	Rod	1.0" Ø x 14.75"	4331	2400°F/1 hr.	118.2[1]	107.5[1]	24.5[1]	32.8[1]	-	-	-	-	-	-	-	0	0
	02A-036-(1-3)	Rod	2.0" Ø x 16.187"	4331	2400°F/1 hr.	105.1[1]	96.6[1]	1.8[1]	87.5[4]	31[1]	-	-	-	-	-	-	0	0
	02A-035-(1-5)	Bar	0.750" x 0.750" x 7"	M96	1300°C/1 hr.	103.6[1]	98.2[1]	1.2[1]	12.8[4]	1.26	-	-	-	-	-	-	0	0
	02A-032-(1-6)	Bar	1.375" x 2" x 5"	M97	1300°C/1 hr.	95.7[1]	94.0[1]	0.36[1]	25.3[4]	2.8	-	-	-	-	-	-	0	0
	02A-033	Bar	1.375" x 2" x 5"	M92	1300°C/1 hr.	130.5[1]	105.4[1]	1.3[1]	29.4[4]	12.8	-	-	-	-	-	-	0	0
Mo-TZM	SPECIFICATION	Rod	CMX-WB-TZM-2			Min. 115	Min. 100	Min. 18	No Requirement				Mid-Radius Min. 260	Mid-Radius Max. 320			Stress Relieved	
	02A-004	Rod	0.125" Ø x 36"	5960	2200°F/¼ hr.	117.8[1]	103.6[1]	32[1]	-	-	-	-	268	293	-	-	-	-
	02A-005	Rod	0.500" Ø x 36"	7468	2250°F/½ hr.	133.7[1]	131.6[1]	28[1]	-	-	-	-	292	306	-	-	-	0
	02A-072	Rod	0.500" Ø x 18"	7498	2250°F/½ hr.	135.3[1]	124.3[1]	27[1]	-	-	-	-	281	299	-	-	-	-
	02A-006	Rod	0.875" Ø x 16"	7473	2300°F/3/4 hr.	125.2[1]	107.8[1]	29[1]	-	-	-	-	276	287	-	-	-	0
	02A-071	Rod	0.875" Ø x 24"	7876	2300°F/3/4 hr.	122.9[1]	104.1[1]	30[1]	-	-	-	-	279	289	-	-	-	-
	02A-081	Rod	0.875" Ø x 12"	7876	2300°F/3/4 hr.	122.9[1]	104.1[1]	30[1]	-	-	-	-	279	289	-	-	-	0

TABLE IV. (Cont'd.)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Final Heat Treatment	Room Temperature Tensile Properties Ult. Ksi	0.2%Y.S. Ksi	Elong. %	2400°F Stress-Rupture Life at 19,000 psi Hours	Elong,%	Bend or Flare	Hardness Bulk	Micro (DPH) Surface	Micro (DPH) Center	Grain Size Vendor ASTM No.	Grain Size GE ASTM No.	Recrystallization (%) Vendor	Recrystallization (%) GE
Mo-TZM	02A-007	Rod	2.0" Ø x 24"	7555	2350°F/1 hr.	104.9[1]	89.1[1]	16.5[1]	-	-	-	-	268	272	-	-	-	
	02A-070	Rod	2.125" Ø x 12"	7893	2350°F/1 hr.	103.9[1]	87.9[1]	18[1]	-	-	-	-	262	280	-	-	-	-
Cb-132M	SPECIFICATION	Rod	01-0010-01-A			Max. 190	Max. 160	Min. 20	Min. 20				Max. 50 Variance		Min. 4		Max. 5	
	02A-055-(1-3)	Rod	1.0" Ø x 22"	66-95119	2400°F/1 hr.	138.8[1]	115.8[1]	11[1]	10.3[1]	26[1]	-	-	281	310	-	9-10	0	50
	02A-041-(1-2)	Rod	2.0" Ø x 24"	66-95119	2400°F/1 hr.	136.1[5]	120.2[5]	3.8[5]	>37[5]	>15[5]	-	-	292	300	-	-	0	0
Cb-1Zr	SPECIFICATION	Bar, Rod, Sheet, Plate, and Strip - 01-0003-04-B				Max. 75	Max. 60	Min. 10			(60°) 1.15 x Diameter	$90R_b$ Max.	Max. 50 Variance		Min. 3			
	02A-022-(1-6)	Sheet	0.0175" x 12" x 24"	912-70112	2200°F/1 hr.	40.7[1]	26.6[1]	29.7[1]	-	-	-	$90R_b$	89	98	8.5	-	-	-
	02A-034-(1-2)	Sheet	0.030" x 24" x 32"	912-70112	2200°F/1 hr.	44.1[1]	32.3[1]	28.7[1]	-	-	-	$97R_b$	95	110	7.5	-	-	-
	02A-023	Sheet	0.125" x 4" x 12"	70112	2200°F/1 hr.	60.6[1]	52.0[1]	13.3[1]	-	-	-	$90R_b$	151	139	7.5	-	-	-
	02A-019	Sheet	0.250" x 6" x 36"	912-70112	2200°F/1 hr.	60.6[1]	52.0[1]	13.3[1]	-	-	-	$90R_b$	151	139	7.5	-	-	-
	SPECIFICATION	Seamless Tubing - 01-0004-01-D				Max. 75	Max. 60	Min. 10			(60°) 1.15 x Diameter	$90R_b$	Max. 50 Variance		Min. 6		100	
	02A-050	Tube	0.250" OD x 0.062" W x 60"	70303	2200°F/1 hr.	61.4[1]	45.8[1]	23[1]	-	-	To 60%	-	116	96	6.5	-	80-90	-
	SPECIFICATION	Seamless Tubing and Pipe - 01-0004-01-C				Max. 75	Max. 60	Min. 20				$90R_b$	Max. 50 Variance					
	02A-040-(1-2)	Tube	0.5" OD x 0.040" W x 3-5'	5886	2200°F/1 hr.	49.2	32.6	42	-	-	To 15%	-	129	141	8	-	100	-
	SPECIFICATION	Seamless Tubing - 01-0004-03-B				Max. 75	Max. 60	Min. 20				$90R_b$	Max. 50 Variance		Min. 3		100	
	02A-029	Tube	2.75" OD x 0.125" W x 48"	5886	2200°F/1 hr.	39.4	22.2	48	-	-	To 3.16"	-	22 Variance		6	6	-	25
	SPECIFICATION	Bar and Rod - 01-0052-01-C				Max. 75	Max. 60	Min. 20				$90R_b$			Min. 4		100	
	02A-069	Rod	0.250" Ø x 60"	6075	2200°F/1 hr.	40.0[1]	24.2[1]	46.5[1]	-	-	-	-	92	86	8.5	-	-	-
	SPECIFICATION	Bar, Rod, Sheet, Plate, and Strip - 01-0003-04-B				Max. 75	Max. 60	Min. 10			(60°) 1.15 x Diameter	Max. $90R_b$			Min. 3			
	02A-020-(1-2)	Rod	0.5" Ø x 120"	911-53002	2200°F/1 hr.	42.2[1]	23.2[1]	43.5[1]	-	-	-	$75R_b$	80	85	1-9	-	-	-
	02A-024	Rod	0.5" Ø x 120"	911-70559	2200°F/1 hr.	41.8[1]	26.2[1]	41.5[1]	-	-	-	$86R_b$	86	85	7	-	-	-
	02A-026	Rod	0.625" Ø x 12"	911-70559	2200°F/1 hr.	43.5[1]	24.2[1]	44[1]	-	-	-	$86R_b$	100	102	7.5	-	-	-

TABLE IV. (Cont'd.)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Final Heat Treatment	Room Temperature Tensile Properties Ult. Ksi	Room Temperature Tensile Properties 0.2%Y.S. Ksi	Room Temperature Tensile Properties Elong. %	2400°F Stress-Rupture Life at 19,000 psi Hours	2400°F Stress-Rupture Life at 19,000 psi Elong,%	Bend or Flare	Hardness Bulk	Hardness Micro (DPH) Surface	Hardness Micro (DPH) Center	Grain Size Vendor ASTM No.	Grain Size GE ASTM No.	Recrystallization (%) Vendor	Recrystallization (%) GE
Cb-1Zr	02A-025	Rod	1.25" Ø x 24"	912-900	2000°F/1 hr.	41.6[1]	32.1[1]	29[1]	-	-	-	$98R_b$	108	136	4-4.5	-	-	-

* Fansteel heat treatment 1475°C or 2685°F.

**Material given an additional 3000°F/1-hr. anneal before usage in loop fabrication.

[1] Average of two tests.

[2]

Product Diameter or Thickness, Inches	Minimum Allowable ASTM Grain Size Number	% R_x Minimum
0.125 to 0.250	4	100
0.250 to 0.500	4	100
0.500 to 1.0	4	100
1.0 to 2.0	4	95
Greater than 2.0	3	90

[3] Heat treated at General Electric at 3000°F/ 1 hour which is a thermal treatment superimposed on materials present thermal condition.

[4] 2400°F @ 30,000 psi., 2 specimens

[5] 2200°F @ 30,000 psi., 3 specimens

TABLE V. RESULTS OF NONDESTRUCTIVE QUALITY ASSURANCE TESTS OF REFRACTORY ALLOY MILL PRODUCTS

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Nondestructive Tests Penetrant	Nondestructive Tests Ultrasonic	Nondestructive Tests Hydrostatic
T-111	02A-065-(1-3)	Sheet	0.035" x 1" x 14"	65076	100% Passed	100% Passed	-
	02B-010-(1-2)	Sheet	0.040" x 12" x 50"	111-D-1632	100% Passed	100% Passed-Numerous small indications <60% amp.	-
	02A-057	Sheet	0.125" x 6" x 10"	65076	100% Passed	100% Passed	-
	02B-009	Plate	0.500" x 6.125" x 11"	111-D-1632	100% Passed	100% Passed	-
	02A-056	Plate	0.500" x 6.125" x 11"	65076	100% Passed	100% Passed	-
	02A-066-(1-3)	Tube	0.375" OD x 0.065" W x 144"	111-D-1670	Failed-Defects Removed	Failed-Defects Removed	Passed
	02A-067-(1-18)	Tube	0.375" OD x 0.065" W x 72"	111-D-1670	Failed-Defects Removed	Failed-Defects Removed	Passed
	02A-068-(1-2)	Tube	1.0" OD x 0.100" W x 140"	111-D-1670	Failed-Defects Removed	Failed-Defects Removed	Passed
	02A-074	Tube	1.0" OD x 0.100" W x 112"	111-D-1670	100% Passed	100% Passed	Passed
	02A-075-(1-2)	Tube	1.0" OD x 0.100" W x 9'	111-D-1670	100% Passed	100% Passed	Passed
	02A-079-(1-2)	Tube	2.250" OD x 0.375" W x 15"	111-D-1765	100% Passed	100% Passed-1 piece with small groove running around end 0-75% amp. (Visual)	-
	02A-085	Tube	2.5" OD x 1.610 ID x 13"	111-D-1102	100% Passed	100% Passed	-
	02A-080	Tube	2.50" OD x 1.610" ID x 13"	111-D-1765	100% Passed	100% Passed	-
	02A-046-(1-2)	Tube	3.0" OD x 0.375" W x 13"	111-D-1102	100% Passed	100% Passed	-
	02A-048	Tube	3.25" OD x 0.250" W x 14"	111-D-1102	100% Passed	100% Passed	-
	02A-045	Tube	3.25" OD x 0.500" W x 14"	111-D-1102	100% Passed	100% Passed	-
	02A-086	Tube	3.25" OD x 0.25" W x 14"	111-D-1829	100% Passed	100% Passed	-
	02A-087	Tube	3.25" OD x 0.500" W x 14"	111-D-1829	100% Passed	100% Passed	-
	02B-004	Rod	0.250" Ø x 24"	111-D-1633	100% Passed	100% Passed	-
	02A-054	Rod	0.250" Ø x 24"	65076	Failed-Defects Removed	100% Passed	-
	02B-005	Rod	0.500" Ø x 48"	111-D-1633	100% Passed	100% Passed	-
	02A-052	Rod	0.500" Ø x 48"	65076	100% Passed	100% Passed	-
	02B-006	Rod	0.625" Ø x 14"	111-D-1633	100% Passed	100% Passed	-
	02A-053	Rod	0.625" Ø x 14"	65076	100% Passed	100% Passed	-
	02B-007-(1-2)	Rod	1.0" Ø x 42"	111-D-1633	100% Passed	100% Passed	-

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TABLE V. (Cont'd.)

Alloy	MCN Number	Mill Product Form	Mill Product Size	Heat Number	Nondestructive Tests Penetrant	Nondestructive Tests Ultrasonic	Nondestructive Tests Hydrostatic
T-111	02A-062	Rod	1.0" Ø x 42"	65076	100% Passed	100% Passed	-
	02B-008	Rod	1.125" Ø x 8"	111-D-1633	100% Passed	100% Passed	-
	02A-061	Rod	1.125" Ø x 8"	65076	100% Passed	100% Passed	-
	02B-014	Rod	1.5" Ø x 6"	111-D-1633	100% Passed	100% Passed	-
	02A-058	Rod	1.50" Ø x 6"	65076	100% Passed	100% Passed	-
	02A-044-(1-3)	Rod	2.0" Ø x 21"	111-D-1102	100% Passed	100% Passed	-
	02A-082	Rod	2.0" Ø x 24"	111-D-1829	100% Passed	100% Passed	-
	02A-038	Rod	2.5" Ø x 21-1/16"	111-D-1670	100% Passed	100% Passed	-
	02A-077	Rod	2.5" Ø x 5.188"	111-D-1765	100% Passed	100% Passed	-
	02A-083	Rod	2.5" Ø x 5"	111-D-1829	100% Passed	100% Passed	-
	02A-076	Rod	3.125" Ø x 16"	111-D-1765	100% Passed	1 indication 100%, 6¼" from noted end (Removed)	-
	02B-013-(1-3)	Bar	1" x 1" x 12.5"	111-D-1633	100% Passed	100% Passed	-
	02A-051	Bar	1" x 1" x 12.5"	65076	100% Passed	100% Passed	-
	02A-047	Bar	1" x 2" x 32"	111-D-1102	100% Passed	2 indications of 90% and 100%, 5¼" from noted end bottom side, 2'5¼" from noted end, top side.	-
	02A-078	Bar	1" x 2" x 63"	111-D-1765	100% Passed	100% Passed	-
Mo-TZC	02A-037-(1-3)	Rod	1.0" x 14.75"	4331	100% Passed	100% Passed	-
	02A-036-(1-3)	Rod	2.0"Øx 16.187"	4331	100% Passed	100% Passed	-
	02A-035-(1-5)	Bar	0.750" x 0.750" x 7"	M96	100% Passed	100% Passed	-
	02A-032-(1-6)	Bar	1.375" x 2" x 5"	M97	100% Passed	100% Passed	-
	02A-033	Bar	1.375" x 2" x 5"	M92	100% Passed	100% Passed	-
Mo-TZM	02A-004	Rod	0.125" Ø x 36"	5960	100% Passed	-	-
	02A-005	Rod	0.500" Ø x 36"	7468	100% Passed	-	-
	02A-072	Rod	0.500" Ø x 18"	7498	100% Passed	100% Passed	-
	02A-006	Rod	0.875" Ø x 16"	7473	100% Passed	-	-
	02A-071	Rod	0.875" Ø x 24"	7876	100% Passed	-	-

TABLE V. (Cont'd.)

Alloy	MCN Number	Mill Product		Heat Number	Nondestructive Tests		
		Form	Size		Penetrant	Ultrasonic	Hydrostatic
Mo-TZM	02A-081	Rod	0.875" Ø x 12"	7876	100% Passed	100% Passed	-
	02A-007	Rod	2.0" Ø x 24"	7555	100% Passed	100% Passed	-
	02A-070	Rod	2.125" Ø x 12"	7893	100% Passed	100% Passed	-
Cb-132M	02A-055-(1-3)	Rod	1.0" Ø x 22"	66-95119	—	100% Passed	-
	02A-041-(1-2)	Rod	2.0" Ø x 24"	66-95119	—	100% Passed	-
Cb-1Zr	02A-022-(1-6)	Sheet	0.0175" x 12" x 24"	912-70112	100% Passed	100% Passed	-
	02A-034-(1-2)	Sheet	0.030" x 24" x 32"	912-70112	100% Passed	100% Passed	-
	02A-023	Sheet	0.125" x 4" x 12"	70112	100% Passed	100% Passed	-
	02A-019	Sheet	0.250" x 6" x 36"	912-70112	100% Passed	100% Passed	-
	02A-050	Tube	0.250" OD x 0.062" W x 60"	70303	100% Passed	Failed-8 indications >40%	-
	02A-040-(1-2)	Tube	0.5" OD x 0.040" W x 3-5'	5886	100% Passed	02A-040-1-Failed, 7 indications >80%	Satisfactory
	02A-029	Tube	2.75" OD x 0.125" W x 48"	5886	100% Passed	Failed-3 indications 1) 19-24" from ref. end 40-90% amp 2) 32.5-34.5" from ref. >40% amp 3) 42-44" from ref. end >40% amp	-
	02A-069	Rod	0.250" Ø x 60"	6075	100% Passed	100% Passed	-
	02A-020-(1-2)	Rod	0.5" Ø x 120"	911-53002	100% Passed	100% Passed	-
	02A-024	Rod	0.5" Ø x 120"	911-70559	100% Passed	100% Passed	-
	02A-026	Rod	0.625" Ø x 12"	911-70559	100% Passed	100% Passed	-
	02A-025	Rod	1.25" Ø x 24"	912-900	100% Passed	100% Passed	-

TABLE VI. SUMMARY OF OVERALL QUALITY ASSURANCE TEST RESULTS

Material	Form	Number of Lots	Chemistry		Tensile Properties		Stress-Rupture		Hardness		Grain Size		Penetrant*		Ultrasonic*		Hydrostatic*		Flare		Bend	
			Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed	Passed	Failed
T-111	Foil	6	5	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	0
	Sheet	3	2	1	3	0	2	1	3	0	3	0	6	0	6	0	-	-	-	-	3	0
	Plate	2	1	1	2	0	1	1	2	0	2	0	2	0	2	0	-	-	-	-	-	-
	Tube	13	13	0	13	0	13	0	13	0	13	0	12	23	12	23	35	0	-	-	-	-
	Wire	7	7	0	-	-	-	-	-	-	7	0	-	-	-	-	-	-	-	-	-	-
	Rod	18	18	0	18	0	13	5	18	0	17	1	20	1	20	1	-	-	-	-	-	-
	Bar	4	4	0	4	0	4	0	4	0	3	1	6	0	5	1	-	-	-	-	-	-
Mo-TZC	Rod	2	2	0	2	0	2	0	2	0	-	-	6	0	6	0	-	-	-	-	-	-
	Bar	3	2	1	3	0	3	0	3	0	-	-	7	0	7	0	-	-	-	-	-	-
Mo-TZM	Rod	8	8	0	8	0	-	-	8	0	-	-	8	0	4	0	-	-	-	-	-	-
Cb-132M	Rod	2	2	0	1	1	2	0	2	0	2	0	-	-	5	0	-	-	-	-	-	-
Cb-1Zr	Foil	3	3	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheet	4	4	0	4	0	-	-	4	0	4	0	10	0	10	0	-	-	-	-	-	-
	Tube	3	2	1	3	0	-	-	4	0	4	0	4	0	0	4	4	0	4	0	-	-
	Wire	2	0	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Rod	5	5	0	5	0	-	-	5	0	5	0	6	0	6	0	-	-	-	-	-	-
Ta	Foil	1	1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Sheet	2	2	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Wire	1	1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Rod	3	3	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Bar	4	4	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
T-222	Sheet	1	1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

* Total Number of Pieces Tested.

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annealed in the same vacuum annealing charge, and has been processed in the same manner in all operations in which the processing temperatures exceeded 500°F.

A listing of the refractory metal and alloy mill products procured for the program, the specifications to which they were procured, and the results of the quality assurance tests are presented in Tables II through V. A summary of the quality assurance test results with respect to meeting the requirements of the specification is shown in Table VI.

The failure of numerous pieces of T-111 alloy to meet the stress-rupture life requirements is attributed to the 1475°C (2687°F)/1 hour heat treatment given this material. Samples of these pieces which were annealed a second time for one hour at 3000°F and all specimens from T-111 alloy material which was originally heat treated for one hour at 3000°F passed the stress-rupture life requirements. All of the T-111 alloy that will be used in Corrosion Loop I (T-111) was given a final anneal of one hour at 3000°F.

All of the various ultrasonic defects found in the refractory metal products were removed prior to use with only three exceptions. The ultrasonic defects reported in the 1-inch x 2-inch x 32-inch long T-111 alloy bar (MCN 02A-047), which will be utilized in the construction of the loop condenser, are surface defects which were removed in subsequent machining of the bar. The ultrasonic defects in the 0.5-inch OD x 0.040-inch wall (MCN 02A-040) and 2.75-inch OD x 0.125-inch wall (MCN 02A-029) Cb-1Zr alloy tubes were not removed since the tubes are to be used in non-critical applications in the lithium distillation facility and are not an intergral part of Corrosion Loop I (T-111).

It should be noted that the material specifications for the Mo-TZC and Cb-132M alloys were prepared from extremely limited data, and the apparent failure of the Mo-TZC and Cb-132M alloys to meet the specifications in certain areas does not imply that the material is inferior. It is anticipated that the data obtained on these materials, both from the vendor and work done at

General Electric, SPPS,[1] will make possible the preparation of improved specifications and aid in selecting processing parameters which will result in improved material properties.

B. ALKALI METAL PURIFICATION

The lithium still was outgassed at elevated temperatures for two months, thereby attaining a room temperature outgassing rate of 2 micron-liters per hour at a pressure of 1.2×10^{-7} torr. Lithium distillation was initiated; however, as a result of an instrumentation failure in the I-tubes (which indicate the still pot levels) five pounds of lithium overflowed into the receiver. All but one-half pound of lithium was returned to the hot trap through an external line attached to the receiver dip leg. The one-half pound residue, which remained in the receiver, will be diluted with two five-pound batches of distilled lithium, each batch being returned to the hot trap. An additional five pounds will be distilled into the receiver for analytical examination and future use. The dilution factor of the one-half pound residue will be 1000 and any impurities contributed by the undistilled lithium will be insignificant.

C. LOOP FABRICATION

The fabrication status of T-111 Corrosion Loop Components is as follows:

1. Slack Diaphragm Transducers

Six T-111 alloy transducer housings were completed and shipped to Taylor Instrument Company for the NaK filling operation. The T-111 diaphragms were electron beam welded to the upper housings which were then tungsten inert gas welded to the lower flanges. The Cb-1Zr ends of the brazed bimetallic joints between Cb-1Zr and Type 316SS were then welded onto the T-111 alloy of the NaK side of the transducers using Cb-1Zr filler metal.

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(1) Advanced Refractory Alloy Corrosion Loop Program, Quarterly Progress Report Number 7 for Period Ending January 15, 1967, NASA Contract NAS 3-6474, NASA-CR-72230, p. 8.

Each transducer was postweld annealed at 2400°F for 1 hour in the R. D Brew Company Model 424B vacuum furnace shown in Figure 4 according to specification SPPS 03-0037-00-A. Chemical analyses of the T-111 sheet specimen used for qualification of this furnace are given in Table VII. The Cb-1Zr to Type 316SS bimetallic joints were positioned outside the heated zone of the furnace (in vacuum). A maximum temperature of 1400°F was recorded on these joints when the T-111 and T-111 to Cb-1Zr welds were at 2400°F.

The completed transducer housings were shipped to Taylor Instrument Company for the NaK filling operation. This vendor was also supplied with a NaK sampler which will be filled with NaK equivalent to that used for the transducers.

2. Lithium and Potassium EM Pump Ducts

Both EM pump duct wrappers have been received. All additional T-111 alloy required to complete both pump ducts was released during this report period and component machining is in progress. All welds required as a part of the manufacturing sequence have been made. It is anticipated that final machining of the helices for the interference fit with the wrappers will be completed by the end of April.

3. Throttle and Isolation Valves

The vendor, Hoke, Inc. has scheduled new delivery dates of April 28 for delivery of the valve bodies and May 15 for delivery of the bellows assemblies.

Four sets of Mo-TZM alloy spur and pinion gears were received.

4. Turbine Simulator

Blade delivery was completed with the receipt of twelve (12) Mo-TZC and six (6) Cb-132M alloy blades. All blades were crack-free and have been released for incorporation in the turbine simulator nozzle assemblies. The machining and assembly of these nozzle stages is now proceeding.

The turbine simulator casings have been received.

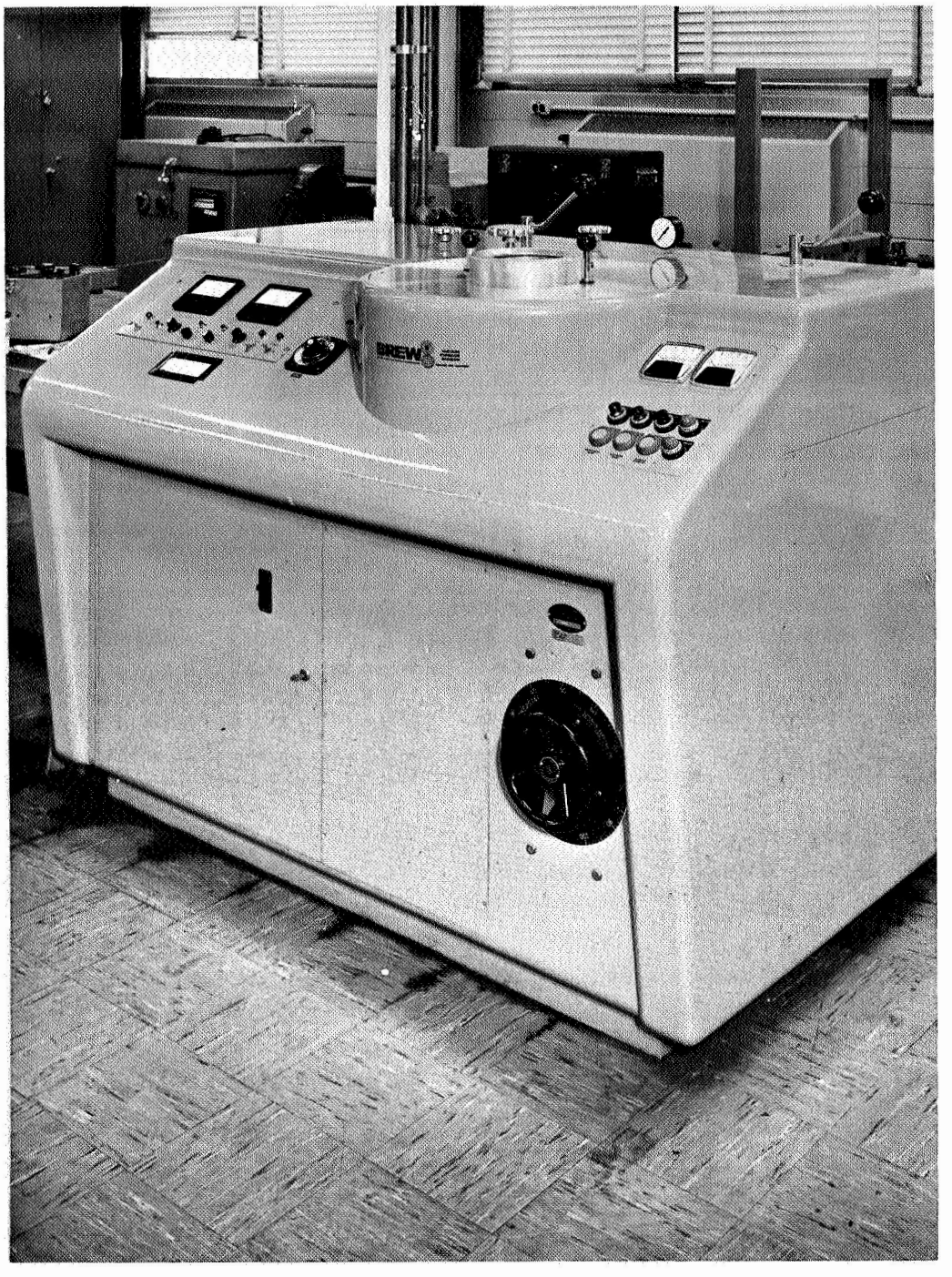

Figure 4. High Temperature Laboratory Vacuum Furnace.
R.D. Brew Company - Model 424B.

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TABLE VII

RESULTS OF CHEMICAL ANALYSES OF T-111 SHEET

FOR HEAT TREATMENT QUALIFICATION

	Pressure, Torr		Element, ppm			
	Start of Run	End of Run	O	N	H	C
Pre-Test Analysis (MCN02B-010)(1)			89	9	1	9,11
Analysis after 2400°F/one hour in SPPS Brew Vacuum Furnace (Model 424B, 4 1/2-Inch Dia x 7-inch)(2)	3.8×10^{-5}	1.4×10^{-5}	54,56	5,7	<1	5,9

C1238-11

(1) 0.040-inch thick sheet.

(2) Specimen wrapped with one overlapped layer of 0.002-inch thick Cb-1Zr foil.

5. Condenser

During this report period two procedures for drilling the center hole in the 1-inch x 2-inch x 31-inch T-111 alloy condenser bar were evaluated. Since initial gun drilling trials had resulted in failure due to a breakage of carbide drills and excessive wear of high speed steel drills, a sample of T-111 alloy was supplied to Standard Tool Company, a producer of gun drills for evaluation. Their report indicated the most success using a high speed gun drill head to which they applied a positive rake chip break along with a 10-degree stack point. Additional material would be required to further define gun drilling parameters.

Concurrent with the above investigation, one 32-inch long condenser bar was committed for conventional drilling. A 0.406-inch diameter hole was drilled successfully using a long fluted twist drill with an extension brazed to the shank. The drill was ground with an included angle of 135 degrees. A hand feed of approximately 0.003-inch per revolution and a drill speed of 6 SFM produced the best cutting action.

After the success of conventional drilling was demonstrated, the 63-inch long condenser bar was cut in half and one additional section was drilled successfully to produce the two sections required for the 60-inch long condenser. These two drilled components were then released for final machining and honing of the inside diameter.

6. Boiler

The welding of the internal tube, spacers, and external tube shell was completed and shipment was made to the boiler forming vendor. Boiler forming will be completed early in the next report period.

7. Stressed Diaphragm Transducer

The electron beam welding of this assembly was completed. EB welding was utilized for joining the diaphragm to the transducer body flanges.

D. QUALITY ASSURANCE

1. Polishing and Pickling of T-111 Tantalum Alloy Tubing

In the post-test metallographic evaluation of loop components following

long time exposure to alkali metals, it is often difficult to determine if the surface irregularities observed on the inner surface of tube wall are a result of corrosion. Quite often, the most that can be stated is that the before test surface and after test surface are similar in appearance. In order to permit a more precise determination of the extent of attack, the smoothness of the ID surface of portions of the T-111 alloy loop tubing is being improved by polishing with 120- and 600-grit alumina cloth followed by pickling in accordance with SPPS Specification Number 03-0010-00-C, "Chemical Cleaning of Columbium, Tantalum, and their Alloys".

The smoothness of the ID surface of transverse tube specimens in the as received, as received and pickled, as polished and as polished plus pickled conditions are shown in Figure 5. The inside surface of the tube specimens was polished by means of a 1/4-inch portable drill with the alumina grit cloth inserted in a slotted rod. The ID of the tube was polished until 0.001-inch was removed from the surface. As shown in Figure 5, the combination polishing and pickling treatment resulted in an essentially smooth surface free of flowed metal.

E. ADVANCED TANTALUM ALLOY CAPSULE TESTS

The ASTAR 811 and ASTAR 811CN alloys were heat treated by Westinghouse at 3000°F for one hour. The heat treated alloys were received on February 23, 1967, and subsequently examined metallographically. The microstructures are shown in Figures 6 and 7 and indicate both alloys to be 100% recrystallized with a grain size of ASTM 6. Considerable second phase precipitate can be seen in the grain boundries and matrix of the ASTAR 811CN alloy. Chemical analyses results before and after heat treatment are presented in Table VIII along with the vendor's ingot analysis. The tungsten concentration of the ASTAR 811CN alloy, 6.4%, is considerably below the nominal concentration of 8%.

Specimens of ASTAR 811 and ASTAR 811CN measuring approximately 1-inch wide and 34-inches long were heated by direct resistance to 2400°F in a vacuum of 1×10^{-6} torr maintained by an oxygen leak for 30 hours according to the procedures previously developed to contaminate similar T-111 alloy

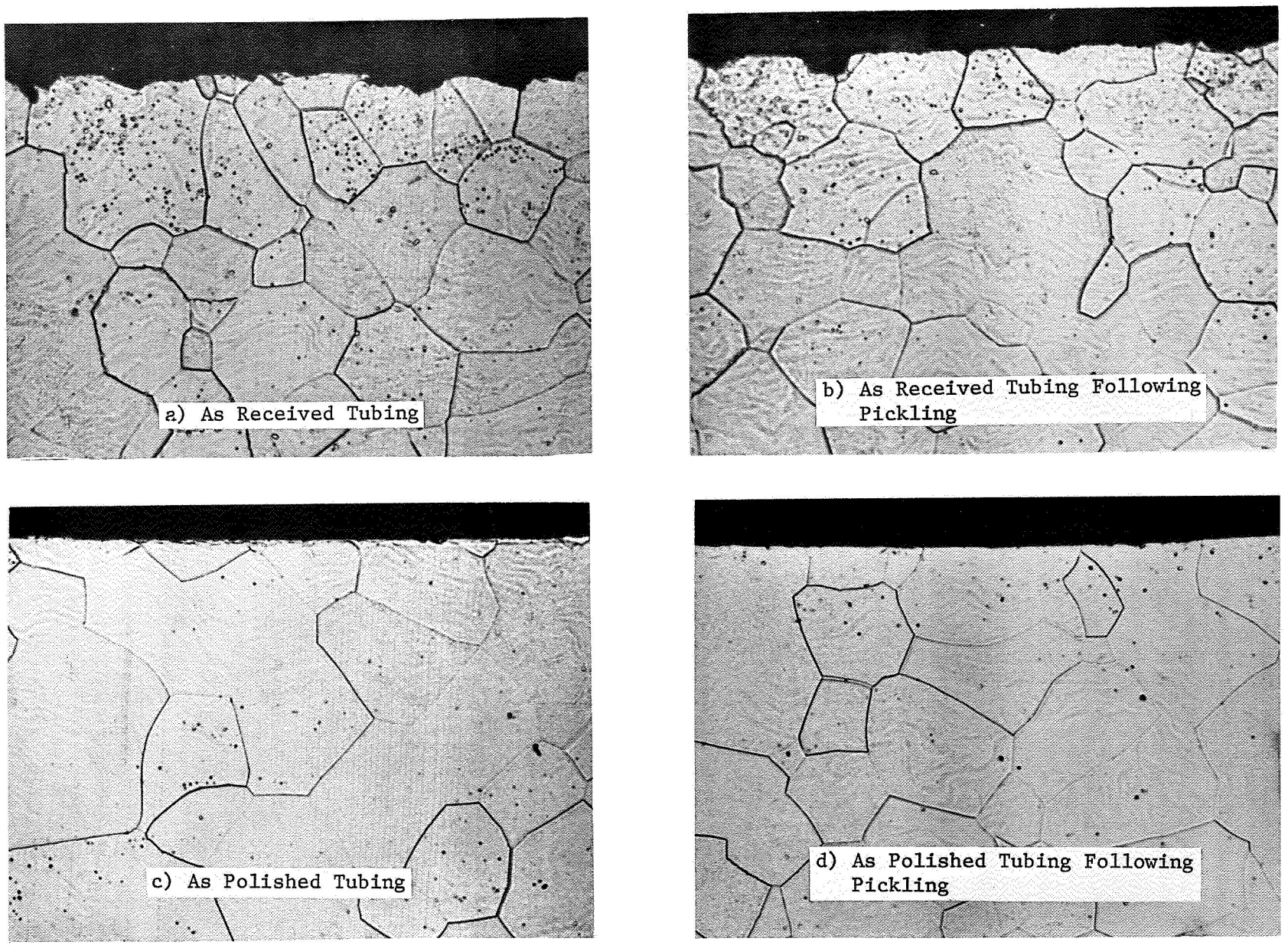

Figure 5. Effect of Polishing and Pickling on the Surface Roughness of T-111 Tantalum Alloy Tubing (0.375-Inch OD x 0.065-Inch Wall). Polishing to Remove 0.001 Inch of the Tube Wall Performed With 120 and 600 Grit Alumina Cloth. Specimens Pickled for Five Minutes in $HF-HNO_3-H_2SO_4-H_2O$, (1-4-1-2, Parts by Volume).

Metallographic Etchant: 30g NH_4[redacted]-50 ml HNO_3-20 ml H_2O

Mag: 500X

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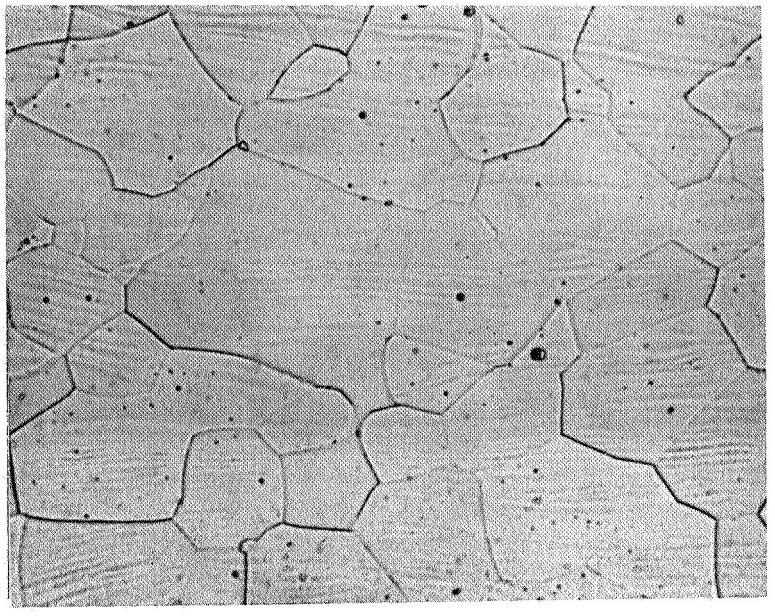

Figure 6. Microstructure of ASTAR 811 Alloy Following Heat Treatment at 3000°F for 1 Hour. Recrystallized with an ASTM Grain Size of 6. (D510111)

Etchant: 30 gm NH_4F-20 ml H_2O-50 ml HNO_3 Mag: 500X

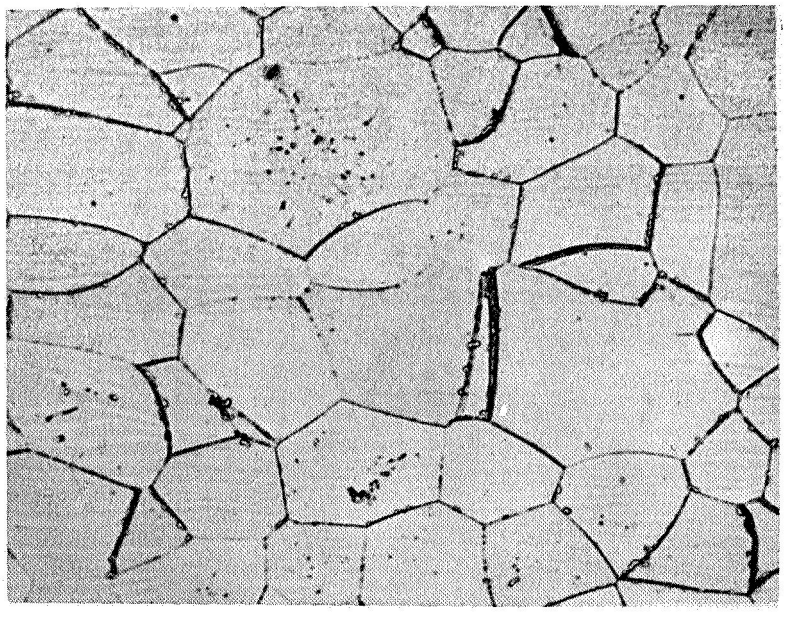

Figure 7. Microstructive of ASTAR 811CN Alloy Following Heat Treatment at 3000°F for 1 Hour. Recrystallized with an ASTM Grain Size of 6. (D510211)

Etchant: 30 gm NH_4F-20 ml H_2O-50 ml HNO_3 Mag: 500X

TABLE VIII: CHEMICAL ANALYSIS OF THE ADVANCED TANTALUM ALLOYS

ALLOY	ELEMENT	NOMINAL	INGOT[1] TOP	INGOT[1] BOTTOM	SHEET (0.040-INCH THICK) BEFORE HEAT TREATMENT	SHEET (0.040-INCH THICK) AFTER HEAT TREATMENT[2]
ASTAR 811	W	8%[3]	7.8%	7.5%		
	Hf	1%	0.95%	1.06%		
	Re	1%	1.04%	0.99%		
	C	-	9ppm	16ppm	14,24 ppm	12ppm
	N	-	10ppm	13ppm	17,6ppm	2ppm
	O	-	12ppm	20ppm	17,11 ppm	16ppm
	H	-	-	-	1,1 ppm	>1ppm
ASTAR 811CN	W	8%	6.5%	6.4%		
	Hf	1%	0.98%	1.01%		
	Re	1%	1.05%	1.01%		
	C	120ppm	130ppm	110ppm	125,129 ppm	127ppm
	N	120ppm	130ppm	110ppm	147,149 ppm[1]	151,152ppm[1]
	O		18ppm	18ppm	12,21 ppm	1,17ppm
	H				5,2ppm	2,<1ppm

(1) Vendor's analysis

(2) 1 hour at 3000°F

(3) Weight percent

C1238-14

specimens[2]. The 1 x 10^{-6} torr atmosphere in the vacuum chamber was monitored with a G.E. partial pressure gas analyzer, shown in Figure 8. This mass spectrometer device is a magnetic deflection instrument with a Nier type of electron bombardment ion source and electron multiplier detector. Although the oxygen partial pressures and specimen temperatures were rigorously controlled, post test chemical analyses indicated considerable differences in oxygen concentration between the ASTAR 811 and ASTAR 811CN alloys. Six duplicate analyses were performed on specimens taken from various regions of the sheet of each alloy. The ASTAR 811 average oxygen concentration was found to be 490 ppm* as compared to an average oxygen concentration of 590 ppm** for the ASTAR 811CN alloy. The contamination specimens have been cut to appropriate sizes for construction of the capsules. Further fabrication of the potassium reflux capsules is pending on the results of the preliminary capsule test. This capsule will be put on test in the next report interim.

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(2) Advanced Refractory Alloy Corrosion Loop Program, Quarterly Progress Report Number 6 for Period Ending October 15, 1966, NASA Contract NAS 3-6474, NASA CR-72177, p 17.

* 459 ppm minimum to 580 ppm maximum

** 540 ppm minimum to 740 ppm maximum

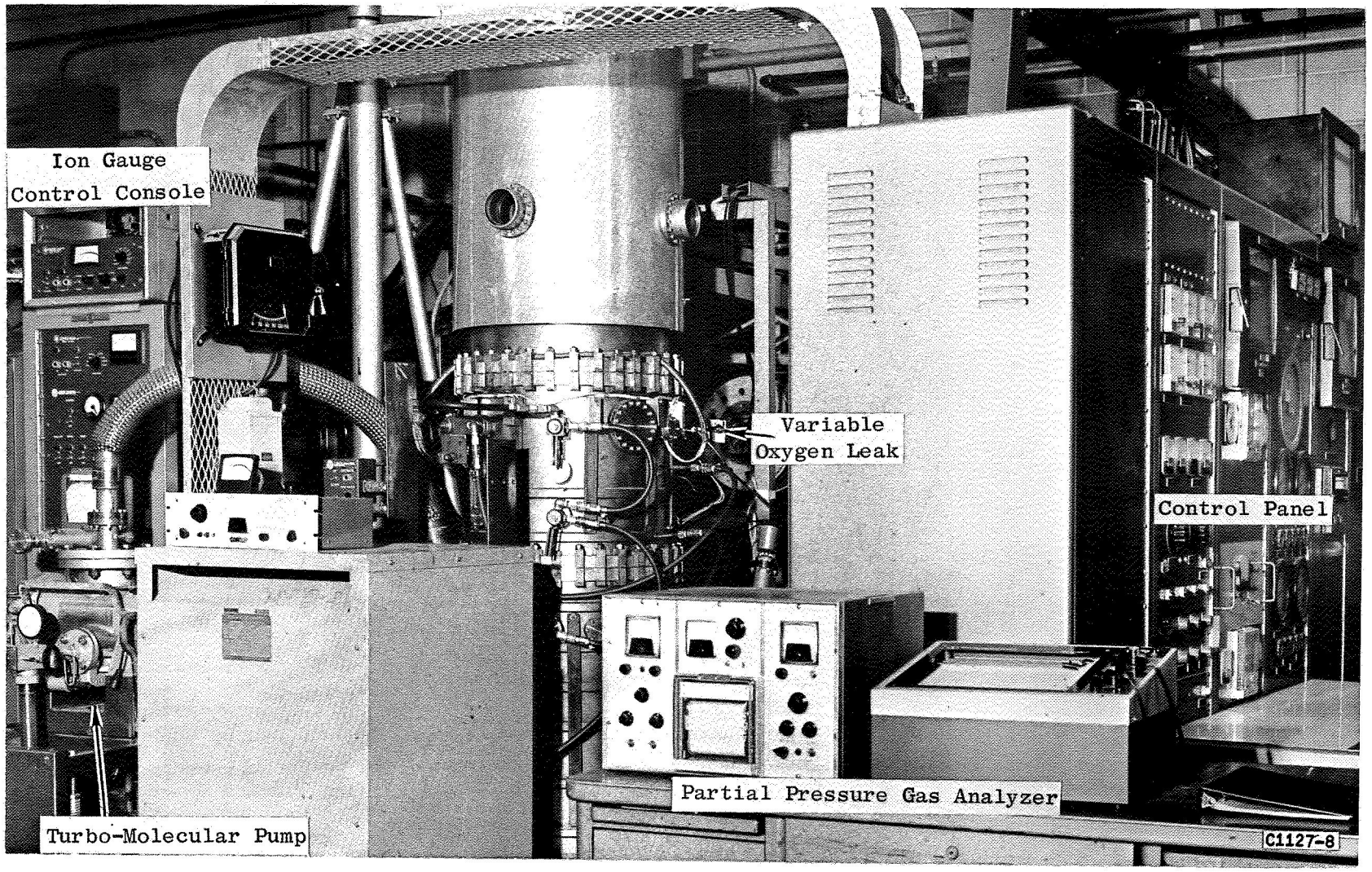

Figure 8. High Vacuum System (10^{-10} Torr Range) Used for the Contamination of the ASTAR+T-111 Alloy Specimens. The chamber is 24 Inches in Diameter and 54 Inches High and Incorporates a 1000 liter/sec. Getter-Ion Pump. The Oxygen Partial Pressure is Controlled by a Variable Leak and Monitored with a Partial Pressure Gas Analyzer.

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(Orig. C66080914)

IV. FUTURE PLANS

A. Complete the fabrication of major components and sub-assemblies for Corrosion Loop I (T-111).

B. A sample of distilled lithium will be analyzed.

C. The preliminary capsule test will be completed and weld specimens of the ASTAR 811 and ASTAR 811CN alloys will be prepared.

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